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

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CHAPTER 1

General Introduction

Inductive reasoning and more specifically, analogical reasoning, is a basic process involved in a wide range of higher cognitive processes and is often seen as representing a core component of intelligence (Halford, 1993; Morrison et al., 2004). Much research investigated the development of this reasoning process in young children (e.g., Goswami, 2002), including its involvement in instruction (Kolodner, 1997), testing (Tzuriel & Kaufman, 1999) and classroom learning (Csapó, 1997; Tzuriel & George, 2009; Vosniadou, 1989). Various research studies have shown that, even before primary school entry, many children can utilize analogical reasoning if they are given appropriate assistance and already possess some domain knowledge of the relationships upon which the analogical problems are based (e.g., Goswami & Brown, 1989; Klauer & Phye, 2008; Richland, Morrison & Holyoak, 2006; Singer-Freeman, 2005). Nevertheless, the first few years of primary school are a particular time for the rapid development of analogical reasoning ability and, unsurprisingly, this results in variable inter- and intra-individual strategic analogical behavior (e.g., Siegler & Svetina, 2002; Hosenfeld, Van der Maas, & Van den Boom, 1997a, 1997b).

To date, few studies have investigated differences in individual learning trajectories in analogical performance over time. Conclusions with respect to the nature of changes in the ability to reason by analogy have frequently been drawn on the basis of results from cross-sectional training studies (e.g., Brown, 1989; Chen, 1996). Hence, the studies in this dissertation are designed to provide greater insight in the variation between children's inter- and intra-individual learning trajectories in solving and constructing complex analogical tasks. Results are projected to provide detailed accounts of children's (changing) strategic analogical behavior as a consequence of repeated assessments over time, a short (dynamic-test-type) training procedure and a self-construction (transfer) task respectively. To do so, specific methods, designs and analyses will be employed to uncover these children's inter- and intra-individual differences, and so enable us to come to a fine-grained understanding of the variation in their change trajectories.

The Microgenetic Research Method

A specific method for obtaining such fine-grained understanding of inter- and intra-individual differences concerns the microgenetic research method, which involves the close study of children at times when they are likely to display rapid developmental growth. To achieve this, these designs utilize dense sampling of performance over a rather short time period. Development is considered to occur naturally, as, in principle, the practice sessions should include no explicit forms of intervention. Observation of children's responses, when given these repeated practice experiences, enables the researcher to identify changes in reasoning strategies and differential developmental trajectories as they happen (Flynn & Siegler, 2007; Siegler & Crowley, 1991).

While several research traditions (e.g. Piagetian) focus on particular ages in which certain skills or knowledge are obtained, microgenetic research distinguishes itself by investigating *the cognitive change processes* through which development or learning occurs (Siegler, 2006). These processes include, for example, regressions and progressions in more or less advanced strategy use and ways of reasoning and behaving that occur only for a short period of time and right before important strategy changes take place (e.g., Siegler & Stern, 1998; Siegler & Svetina, 2002). Findings from microgenetic research studies have resulted in the assertion that development in various domains, from theory of mind (e.g., Flynn et al., 2004) to mathematical skills (Ven, Boom, Kroesbergen, & Leseman, 2012), involves more than the addition of new strategies to a child's current repertoire. Development involves an improved capacity to select the best problem-solving strategy at any given moment, greater reliance on more advanced strategies, and improved execution of those strategies. To reach these conclusions, microgenetic research studies often utilize video and voice recordings of children's behavior and immediate (retrospective) verbal reports to investigate trial-by-trial strategy use (Siegler, 2006). Likewise, for the studies in this dissertation, video recordings of children's behaviors and immediate (retrospective) verbal reports will be employed to capture cognitive changes as they happen.

Some drawbacks of this type of research are the time and costs involved in the frequent sampling, and detailed analyses, of the observations that are made. To manage the trade-off between these drawbacks and the sample size, the study in Chapter 3 of this dissertation will take the form of a preliminary study with a smaller sample of children, which will be enlarged for the operation of the studies in Chapters 4 and 5.

Dynamic Testing

Repeated assessments, such as those utilized in microgenetic research, involve 'unprompted' practice experiences that draw upon an essentially static procedure (Sternberg & Grigorenko, 2002). A more dynamic form of assessment, however, demonstrating what children can achieve when they are provided with tailored assistance during the testing procedure, may add important information about children's potential, should they be given an appropriate educational program (Grigorenko, 2009; Resing & Elliott, 2011; Swanson & Lussier, 2001).

Dynamic testing, therefore, has become increasingly popular for the study of inductive reasoning (e.g., Bethge, Carlson, & Wiedl, 1982; Resing, 2000; Tzuriel, 2000; Tzuriel & Flor-Maduel, 2010; Tzuriel & Kaufman, 1999). Conventional static tests, administered at a certain moment in time, are considered to be means to measure already developed abilities. Dynamic modes of testing are designed to assess developing or yet-to-develop abilities which are the products of underlying, but often unrecognized, cognitive capacities (e.g., Hessels, 2000; Elliott, 2003; Lidz & Macrine, 2001; Resing, 2006; Sternberg et al., 2002; Sternberg & Grigorenko, 2006). Dynamic testing therefore, has been found a means to gain insight into the cognitive and meta-cognitive strategies used by the examinee, their responsiveness to examiner assistance and support, and their ability to transfer learning from the test situation to subsequent unaided situations (Elliott, 2003).

For the studies in this dissertation (Chapters 3, 4, and 5), therefore, it is considered important to investigate the influence of a dynamic testing approach upon children's inter- and intra-individual developmental trajectories in analogical reasoning.

Unlike most other dynamic test or training formats, the measures that will be used in this dissertation will proceed from difficult to easy items. Where children need assistance, a minimum amount of help required to solve the tasks independently will be provided. The nature of the help that will be provided will be in accordance with Resing's (e.g., 1993, 1997) graduated-prompts dynamic test format. This 'technique' was originally pioneered by Campione, Brown, Ferrara, & Steinberg (1985) and has been successfully utilized in several subsequent studies (e.g., Resing, 2000; Resing & Elliott, 2011; Wang, 2010, 2011a,b; Resing, Xenidou-Dervou, Steijn, & Elliott, 2012). This type of procedure involves the use, during the dynamic testing session, of a series of adaptive and standardized, hierarchically ordered, metacognitive (self-regulating) and cognitive (task-specific) prompts that proceed from general to increasingly task-specific, and are only provided if a child is unable to proceed independently. As such, a minimum number of prompts, which are increasingly explicit, are provided until the child reaches the correct solution.

Multilevel Analysis

Typically, microgenetic research data sets are analyzed both qualitatively and quantitatively. Qualitatively, graphical techniques are often used to display various cognitive changes over time (Siegler, 2006). In this dissertation, every study will utilize a variety of graphical techniques to provide more in-depth understanding of the (quantitative) findings. Quantitatively, repeated-measures ANOVA has been widely used to analyze longitudinal data involving repeated measurements of the same individuals. This more traditional type of analysis will be utilized in Chapter 2.

However, repeated-measures ANOVA does not enable the researcher to analyze individual children's trajectories of performance and take individual variation into account. These weaknesses can be overcome by viewing microgenetic data sets as comprising a specific instance of multilevel data, where repeated measurements are nested within individuals. Generally, multilevel regression models involve hierarchically structured data, where lower level observations are nested within higher level(s). As such, employees can be nested in firms or students in schools (Hox, 2002, 2010; Kreft & De Leeuw, 2007; Snijders & Bosker, 1999; Van der Leeden, 1998).

In the case of this dissertation (Chapters 3 and 4), repeated measurements will be viewed as nested within individuals, where the test sessions that children receive will be modeled at the first level and individual children at the second level. By creating a model with varying regression coefficients at the session level (Level-1), multilevel analysis will be able to include growth trajectories that vary for each individual child (Level-2). An additional feature of multilevel analysis is the possibility to include two types of explanatory variables in the model: time constant and time varying variables. This feature will enable the modeling of both the average growth trajectories of each group, as well as the individual growth trajectories of each child (Hox, 2002, 2010). Thus, analyzing microgenetic data with multilevel analysis will allow not only for the inspection of learning trajectories (Level-1) for each individual (Level-2), but also the inspection of systematic variation between these trajectories as a function of background variables (such as working-memory) and experimental treatment (dynamic testing) (Van der Leeden, 1998).

Analogical tasks, sometimes incorporating dynamic testing procedures (Grigorenko, 2009), have been employed for the purposes of differentiating and, potentially, predicting (young) children's cognitive development and educational progress. To achieve these goals, in-depth, fine-grained understanding of children's developmental trajectories at various ages is needed. Here, the use of a microgenetic research design may prove especially helpful (e.g. Siegler & Svetina 2002; Tunteler & Resing, 2007a,b).

The Overlapping Waves Theory

Microgenetically observed cognitive changes and variations between individual children could be meaningfully interpreted by Siegler's (1996) overlapping waves theory. This theory co-evolved alongside the microgenetic research method to interpret microgenetic research outcomes. Interpretations of research outcomes are made along five dimensions of cognitive change: the source, rate, path, breadth and variability of change.

The Source of Change

The source of change refers to underlying factors that encourage changes in reasoning (Siegler, 2006). Two related sources of change are the age of the child and repeated practice experiences. Repeated practice experiences at an age when children are likely to display rapid developmental growth in the area of interest, are thought to accelerate natural development (Siegler, 2006). In Chapters 2-5 it will be investigated whether repeated practice experiences are sufficient to accelerate growth in analogical performance in children attending 1st grade (Chapter 2) and 2nd grade (Chapters 3-5).

A second source of change that will be considered in this dissertation is training in analogical reasoning. It is considered that the acquisition and development of cognitive abilities may show differing pathways when acquired through instruction than as a result of more 'natural' unprompted opportunities. These potentially differing pathways make it useful to examine both in combination (Kuhn, 1995; Bjorklund, Miller, Coyle & Slawinsky, 1997; Opfer & Siegler, 2004). Therefore, in addition to unprompted repeated practice, instruction derived from two types of training will be included. These will be based on the component processes of analogical reasoning put forward by Sternberg and Rifkin (1979): encoding, inference, mapping and application. Other studies have successfully used these component processes to train young children in analogical reasoning as well (e.g., Alexander et al., 1989; Resing, 1990, 2000; White & Caropreso, 1989).

In the studies reported in this dissertation, repeated practice and training tasks will consist of pen-and-paper open-ended classical geometrical analogical tasks (Chapter 2) and open-ended figural matrix analogical tasks (Chapters 3 and 4). The study in Chapter 2 will include a short training procedure that will consist of a standardized step-by-step procedure, which will prompt children to explain the reasoning behind the experimenters' correct analogical solution. Explaining the nature of the correct solutions of a more knowledgeable person has been found to induce learning (Siegler, 1995; Siegler, 2002; Rittle-Johnson, 2006). In Chapters 3 and 4 a dynamic test approach will be taken to train children. Key to this approach is the incorporation of feedback and training during the testing phases (Sternberg & Grigorenko, 2002; Elliott, 2003; Swanson & Lussier, 2001).

A third source of change considered is working-memory, a process that will be considered in every phase of this dissertation. Working-memory may be thought of as the workspace for the construction of relational representations for solving a given analogical task while using knowledge stored in semantic memory. This workspace is limited in the number of relations that can be processed in parallel although these typically increase with age and maturation. However, complex relations can be recoded into representations of lower complexity or be segmented into smaller parts in order to process them serially (Halford, Wilson & Philips, 1998, 2010). The type of relationship or task that needs to be managed appears to be influenced by the differential involvement of separate components of working-memory. Various components have been investigated in a variety of inductive reasoning or academic tasks (e.g, Raghubar, Barnes & Hecht, 2010; Alloway & Passolunghi, 2011). The age of the child and the differential involvement of these components in different types of tasks were first demonstrated by Alloway, Gathercole and Pickering (2006). In line with Baddeley and Hitch's (1974) working-memory model, they found that children as young as 4 years exhibit a structural organization of memory into a domain general component for processing information, and verbal and visual-spatial domain specific components for storage. Furthermore, they found that these components could be assessed in a reliable way. In Chapters 3 and 4, the focus is explicitly on the differential involvement of verbal and visual-spatial working-memory components, to examine their possible role in respect of analogical reasoning development in second graders. These components were examined separately with a working-memory assessment that made sufficient storage and processing demands (Alloway, 2007) and which would help us explore their separate influence on analogical reasoning (Resing, et al., 2012).

A fourth source of change that will be investigated concerns children's variability in analogical strategy use. It has been suggested that high initial variability of strategy use often predicts substantial subsequent learning (Siegler, 2006, 2007). Therefore in Chapters 2 (1st grade children) and 4 (2nd grade children) the influence of initial variable analogical strategy use on analogical performance change will be investigated.

The Rate of Change

The rate of performance change in a certain task domain refers to the amount of time and experience a child requires to change from their initial to their current performance, the child's change from initial to consistent adequate performance is referred to as the rate of uptake (Siegler, 2006). In the current dissertation, the rate of change in relation to the above-mentioned sources of change will be investigated. The microgenetic timeline will be inspected for the particular times where children display lesser and greater rates of change. These moments of change will be investigated in relation to sources of change, for example, children's varying (working-memory) capacities, and variable analogical strategy use. The resulting varying developmental trajectories including lesser and greater rates of change of the different analogical performance measures will be made visible through regression lines for the separate conditions (Chapter 2, 3 and 4), smaller subgroups of learners, and individual children within their respective subgroups (Chapters 3 and 4). These smaller subgroups of learners will be based on a combination of background variables (sources of change) to investigate their combined influence on subgroup and individual children's developmental trajectories. In order to do this, in Chapters 3 and 4 a different means of analysis will be used: multilevel analysis (MLA) for longitudinal, repeated measurement data (as described earlier).

The Path of Change

The term, path of change, refers to developmental trajectories in terms of sequences of changing knowledge states and problem-solving behavior (Siegler, 2006). To investigate these, Siegler (2007) posited the benefit of trial-by-trial assessments of strategy use, focusing upon four component processes: 1) acquisition of new strategies; 2) increased usage of the most advanced strategies in the child's current repertoire; 3) increasingly efficient execution of strategies; and 4) improved choices among strategies. In Chapters 2 and 4, a qualitative microgenetic, session-by-session assessment will be 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.

The value of immediate retrospective self-reports of solution strategies together with observations of behavioral solution strategies on the part of children aged five years and older, has been indicated by an increasing body of developmental literature – from arithmetic (Siegler & Stern, 1998) to reading (Farrington-Flint, Coyne, Stiller, & Heath, 2008), to inductive reasoning (Resing, et al., 2012). These self-reports are not expected to impact upon children's developmental trajectories as long as the researcher remains neutral and no feedback is provided (Siegler, 2006). Rather, they may reveal additional information about the depth of understanding children possess about the strategies they employ to tackle the problems (e.g., Siegler & Stern, 1998; Church, 1999).

The Breadth of Change

The breadth of change refers to transfer, to the generalization of newly acquired strategies to other contexts and problems. Transfer of learning has been the subject of research for more than a century (Larsen-Freeman, 2013; Engle, 2012). With reference to dimensions such as content and context (Barnett & Ceci, 2002), researchers have differentiated between surface versus deep transfer (Forbus, Gentner, & Law, 1995), formal versus material transfer (Klauer, 1998), and near versus far transfer. Transfer has been found to occur consciously and unconsciously (Day & Goldstone, 2012; Day & Gentner, 2007), instantaneously and very gradually (Siegler, 2006), after task mastery (Siegler, 2006), or after more variable strategic behavior (Perry, Samuelson, Malloy, & Schiffer, 2010).

Differing findings from transfer studies with both adults and children have been attributed to – among other things – individual differences in study participants, such as differences relating to working-memory and task domain expertise (sources of change) (Day & Goldstone, 2012). More specifically, is has been suggested that individual differences that emerge while solving transfer tasks could be used to identify children's differential potential for learning, by assessing how well they can flexibly use previously learned strategies (Bosma & Resing, 2006; Campione et al., 1985).

Therefore, in Chapter 5 it will be attempted to assess differences in children's learning of analogical strategic behavior – induced by repeated practice experiences with classical figural analogies and a dynamic-test-type training procedure – by assessing children's differences in making so-called analogical construction tasks. For this transfer task, children will no longer be required to solve figural analogies in a classical way of assessment, but instead they will be asked to take a more active role by constructing similar figural analogies for the examiner to solve (Bosma & Resing, 2006).

To encourage transfer of previously learned strategies, the surface commonalities of this analogical construction task will be the same as the open-ended classical figural analogical tasks that children solved during the repeated practice and dynamic training session (i.e. the same matrix-format and the same animal cards exhibiting the same possible transformations that could be constructed with these cards), thereby priming children to use what they will previously have learned (Day & Goldstone, 2012).

Nevertheless, these surface similarities will not necessarily make the process of transfer straightforward. The construction format will be more challenging than the open-ended classical version, since the former will require children to extract analogical strategies from schemas in their memory in order to construct the transformations. Such complexity is not required when tackling the classical format (Martinez, 1999). Effective constructors in the current sample will therefore be regarded as having gained a more thorough or 'deeper' understanding of the underlying principles of the analogical tasks (Harpaz-Itay et al., 2006; Perkins, 1992). As such, providing children the opportunity to move beyond practice experiences and a dynamic training with classical figural analogies to engagement in problem construction, is expected to shed new light on their developing use of strategic reasoning (e.g., Pittman, 1999; May, Hammer, & Roy, 2006; Kim, Bae, Nho, & Lee, 2011; Haglund & Jeppsson, 2012; Siegler, 2006).

Accordingly, the analogical construction task in Chapter 5 serves a twofold purpose. First, it is intended to assess the extent to which children's learning in relation to performance on a traditional analogical task will subsequently transfer to one that will involve construction. Second, it is intended to examine the ways in which this may provide additional information, both qualitative and quantitative, that could be used within a dynamic testing context

(Grigorenko, 2009; Resing, 2013). To achieve this purpose and reveal more clearly the depth of children's strategic reasoning when tackling the analogical construction task, again immediate retrospective self-reports will be employed (e.g., Siegler & Stern, 1998; Church, 1999; Bosma & Resing, 2006).

The variability of change

The variability of change refers to differences between children in the source, rate, path and breadth of change, as well as changes within individual children's array of strategies (Siegler, 2006; 2007). Siegler (2007) posits that cognitive variability is an important variable in understanding, predicting, and describing the amount and type of cognitive change. He refers to cognitive variability as the differences between children in terms of change agents, developmental trajectory, generalization, and speed of change, but also changes within the individual child's repertoire of strategies. As described above, and throughout this dissertation, inter- and intra-individual variable analogical reasoning will be encouraged and investigated both quantitatively and qualitatively, thereby being the most important and complex focus of this study. This focus is both complex and important, since gaining greater understanding of individual children's learning trajectories in relation to various cognitive processes, such as analogical reasoning (e.g., Tunteler, Pronk, & Resing, 2008), is likely to be valuable both for understanding the nature of intellectual development and for informing targeted educational intervention at an early stage (e.g., Grigorenko, 2009).

Outline of the Dissertation

The current dissertation used a microgenetic approach to investigate young children's inter- and intra-individual variable analogical reasoning in accordance with Siegler's (1996) overlapping waves theory, which interprets cognitive change along five dimensions: the source, rate, path, breadth and variability of change.

Chapter 1 introduced the various studies that made up this dissertation and gave an overview of their theoretical and methodological background.

Chapter 2 focused on unprompted changes in children's analogical reasoning on geometric tasks and the additional effect of a short training procedure. This study will took the form of a 5-session microgenetic procedure, with a follow-up test session after 3 months. As such, it aimed to investigate changes in children's analogical performance due to either practice alone or a short training procedure. Moreover, it was examined whether this short training procedure had a greater effect on children showing variable, inconsistent analogical reasoning over trials than on children who fail to show this kind of behavior; and whether changes in analogical reasoning, either because of repeated practice alone or because of the short training procedure, persisted over a period of 3 months. Finally, it was explored whether children's analogical reasoning performance is related to their memory and inductive reasoning skills.

Chapter 3 focused on the inter- and intra-individual developmental trajectories of analogical reasoning with open-ended figural matrix analogies in a dynamic test and non-guided practice setting. In this study, the microgenetic research method was combined with Multilevel Analysis (MLA) to investigate developmental trajectories as a function of their background variables and experimental treatment: a dynamic-test-type training. Background variables included verbal and abstract-visual-spatial working-memory capacity. This study, as mentioned earlier, was a preliminary study for the study in Chapter 4. As such, participants in this study were a subset of the participants included in Chapter 4.

Chapter 4 described the first follow-up study of the investigation of Chapter 3. Here subgroups of children with similar learning trajectories in analogical reasoning were investigated microgenetically and with the use of MLA. Subgroups' inter- and intra-individual paths of change were compared through children's behavioral strategy use and verbal reports thereof. Subgroup categorization was based on condition and potentially important background variables, which included verbal and spatial working-memory, and variable analogical performance.

Chapter 5 described the second follow-up study of the research described in Chapters 3 and 4. This study examined the breadth and depth of progress in analogical performance by means of a transfer task that required children to construct analogies rather than solve them. With respect to this aim, both quantitative and qualitative inter- and intra-individual analogical measures were investigated.

In Chapter 6 the results of the various studies were discussed, as well as the implications of key findings for research and education.

CHAPTER 2

Inter- and intra-individual variability in the process of change in the use of analogical strategies to solve geometric tasks in children: A microgenetic analysis

Tunteler, E., Pronk, C.M.E., & Resing, W.C.M. (2008). Inter- and intra-individual variability in the process of change in the use of analogical strategies to solve geometric tasks in children: A microgenetic analysis. *Learning and Individual Differences, 18*, 44–60.

Abstract

This study focused on unprompted changes in children's analogical reasoning on geometric tasks and the additional effect of a short training procedure. Participants were 36 grade 1 level children (M=6;8 years) divided over a not-trained and a trained condition. The study was a 5-sessions microgenetic procedure, with a follow-up test session after 3 months. The results showed considerable inter-and intra-individual variability in the process of change in the use of analogical strategies in both not-trained and trained children. Repeated practice, without explicit prompting, caused a spontaneous improvement in analogical reasoning. This improvement was mainly due to an increase in implicit analogical reasoning. The short training procedure caused an improvement above and beyond that of practice alone (Estrained/not-trained=.96), inducing in 9 children a continuation of a gradual process of change, while in 4 other children it caused a rather rapid change in analogical performance. The training effect was greatly due to an increase in explicit analogical reasoning. Both effects were still visible after a period of 3 months. Because the study may have implications for geometric learning with young children, the authors recommend further investigations of young children's use of analogies on tasks involving geometric transformations. The authors also recommend further research into transfer to other mathematical competencies to investigate implications for mathematics besides geometry.

2.1 Introduction

Our primary goal in this study was to gain insight into the nature of young children's analogical reasoning ability by investigating whether children's analogical performance changes due to practice alone, without explicit prompting, and whether a short training procedure that provides children with some explicit modeling and feedback improves their performance. Unlike other studies on young children's analogical ability (e.g., Alexander et al., 1989; Brown, 1989; Goswami & Brown, 1989; Hosenfeld, Van der Maas, & Van den Boom, 1997a,b; Tunteler & Resing, 2002), this study investigated children's unprompted analogical performances over a period of weeks both before and after a short training in analogical reasoning. This was compared with the performances of children of the same age who were given multiple practice opportunities over time, but no instructions or explicit prompting.

The ability to reason by analogy has long been regarded as central to human cognition (Goswami, 1991, 1992; Halford, 1993) and as an important skill for classroom learning (e.g., Csapó, 1997; Goswami, 1992; Vosniadou, 1989) and instruction (e.g., Kolodner, 1997). During the past few decades, a considerable number of researchers have focused on understanding the development of this reasoning ability in children (e.g., Alexander et al., 1989; Brown, 1989; Gentner, 1989; Goswami & Brown, 1989; Halford, 1993; Hosenfeld, Van der Maas et al., 1997a,b; Singer-Freeman, 2005; Singer-Freeman & Goswami, 2001). Although these studies have resulted in much information on children's analogical reasoning competency under various circumstances, there is still no consensus about the nature of this reasoning ability in young children. An increasing number of studies, in which a variety of analogy tasks were used, showed that very young children can already reason analogically after a certain amount of help on the condition that they understand the relationships on which the analogies are based (e.g., Brown, 1989; Chen, 1996; Chen & Daehler, 1989, 1992; Singer-Freeman, 2005; Singer-Freeman & Goswami, 2001). In this research tradition, developmental changes in children's analogical reasoning ability is generally assumed to be gradual and quantifiable, and driven by a growing knowledge base or increasing metacognitive skills (Brown, 1989; Goswami, 1991). However, other researchers (e.g., Halford & McCredden, 1998; Halford, Wilson & Phillips, 1998; Hosenfeld, Van der Maas et al., 1997a,b) are more apprehensive about young children's analogical capacity; they posit that developmental changes in analogical reasoning is a matter of changes in global competence. This lack of consensus may cause one to question whether the claim for analogical reasoning at an early age made in some studies might be an artifact of the experimental manipulations in these studies.

Review of the literature on analogical reasoning showed that the conclusions with respect to the nature of changes in the ability to reason by analogy described above were frequently drawn on the basis of results from cross-sectional training studies (e.g., Brown, 1989; Gholson, Morgan, Dattel, & Pierce, 1990; Gentner, 1989; Chen, 1996; Chen & Daehler, 1989, 1992). Yet, Bjorklund, Miller, Coyle and Slawinsky (1997) asserted that natural, unprompted changes, as opposed to changes induced by training, may show a different path. Moreover, various other authors stressed that such single-occasion assessments could produce an incomplete or even over-optimistic picture of the process of change of the cognitive strategy under investigation because they address changes indirectly (e.g., Granott & Parziale, 2002; Kuhn, 1995; Siegler, 1995, 2006).

Despite the many studies in the field of analogical reasoning conducted in the past, very few of them have focused on a comparison of changes over time in children's analogical reasoning performance induced by practice and changes induced by a training procedure.

Two exceptions worth mentioning are the longitudinal studies conducted by Alexander et al. (1989) and Hosenfeld, Van der Maas et al., 1997b). Alexander et al. (1989) used simple 3-dimensional geometric analogical tasks of type A:B::C:D, and monitored the analogical performances of trained 4–5 year-old children and that of not-trained children of the same age over a period of months. They showed that children of this age were able to benefit from an extensive training in analogical reasoning skills, but revealed little about the paths of change in the two conditions. Moreover, it should be noted that the not-trained children in the Alexander et al. (1989) study were repeatedly given explicit instructions to the tasks before and during testing, and explicit instructions may also be seen as a form of training. Hosenfeld, Van der Maas et al. (1997b) observed 6–8 year-old children's analogical performance on paper and pencil classical geometric tasks over a period of months. These authors posited an age-related transition in analogical reasoning on geometric tasks in children of this age. However, the children in their study were given extensive instructions for the tasks, both before and during testing so that we are unable to determine the natural and unprompted analogical reasoning of those children. Such natural reasoning might not proceed in the same way suggested by the sequence of instructions given by Hosenfeld, Van der Maas et al.

More recently Tunteler and Resing (2007a) microgenetically investigated the performances on problem analogy tasks over a period of weeks of 5–7 year-old children who were given repeated practice opportunities without any instruction or feedback in comparison to the performances of children who were previously given a short training consisting of some instructions in how to use analogies. A microgenetic procedure allows close observation of change mechanisms over a relatively short period of time, as well as the identification of the conditions and transition strategies leading up to change (Siegler & Crowley, 1991). The microgenetic procedure used in the Tunteler and Resing study allowed the authors to distinguish three groups of reasoners: 1) children showing consistent analogical reasoning over trials; 2) children showing consistent inadequate, non-analogical reasoning; and 3) children showing variable, adequate and inadequate, reasoning. Some children had difficulty with using analogies despite of the training, while other children of the same age and even some younger children consistently used analogies over trials without reminding. Over time, an increasing number of children, particularly in the trained group, showed very consistent analogical reasoning, while a decreasing number demonstrated inadequate, non-analogical reasoning. However, variable and diverse strategy use over trials existed in a considerable number of both the trained and not-trained children of the two age groups. The authors concluded that variability in strategy use on problem analogy tasks is not only common in situations in which children are not explicitly given instructions as they demonstrated earlier (Tunteler & Resing, 2002, 2007b), but apparently exists in trained children as well.

According to Tunteler and Resing (2007a), this pervasiveness in variability in children's strategy use on analogical problem solving tasks indicates that the ability to reason by analogy on this type of analogy tasks develops over a protracted age range. It also underlines the importance of a microgenetic research method in studying the process of change in the domain of analogical reasoning. Therefore, we realized that in order to gain more insight into the nature of young children's analogical reasoning ability, we needed, in addition to the Tunteler and Resing study, to microgenetically examine changes in young children's analogical reasoning under different conditions–trained and not-trained–on another type of analogy task. In this study we used classical geometric analogy tasks. This type of analogy tasks is said to measure analogical reasoning more purely than verbal analogical tasks, since they need no vocabulary and domain specific knowledge (Goswami, 1992).

The advantages of the microgenetic approach have been extensively described elsewhere (e.g., Kuhn, 1995; Siegler & Crowley, 1991; Siegler, 2006). It should however be noted that even though most older microgenetic studies sought to accelerate the natural process of developmental changes by increasing the density of exercises within the domain under investigation, this research method is not restricted to this purpose (Siegler, 2006). Adding an element of training is assumed to be informative regarding the development of the skills examined (Kuhn, 1995; Opfer & Siegler, 2004). Recently, microgenetic studies have increasingly focused on the effectiveness of various learning experiences (see Siegler, 2006). Our study is similar to this latter type, because it observed changes in children's analogical reasoning performance as a result of practice alone, as well as changes that occurred as a consequence of a short training procedure. Siegler (2006) asserted that change as a result of practice alone, without explicit instructions or prompting, may be considered as natural because it does not arise from explicit interventions. We therefore considered a study that couples observations of children's unprompted analogical performances over time with that as a result of a short training procedure as a valuable tool to increase knowledge of the nature of analogical reasoning in young children.

Because the type of intra-individual variability in strategy use described earlier has been shown to predict later learning substantially (Siegler, 2006), we thought it might be useful to investigate whether a short training procedure would have a greater effect on children showing variable, inconsistent analogical reasoning over trials than in children not showing this kind of behavior. Participants in the study were 6–8 year-old children from first grade. Results of prior studies on analogical reasoning on various types of analogy tasks showed that changes in analogical reasoning are most prominent at this age (e.g., Goswami & Brown, 1989; Hosenfeld, Van der Maas et al., 1997a,b; Tunteler & Resing, 2007a,b).

In the current study, analogical reasoning was measured by a combination of both children's overt solutions to the problems and their verbal explanations for their solutions. Siegler (2006) stated the advantage of using retrospective self-reports of strategy use next to overt solution behavior in studies on strategy development, because self-reports may give additional information about the strategy used. According to Siegler (2006), this additional information would enhance the accuracy of classification of strategy use substantially. We therefore assumed that a combination of both an overt behavior and a verbal measure for analogical reasoning in our study would reveal more about the development of analogical reasoning on classical geometric analogy tasks, than just one measure. Because several authors (e.g., Halford, 1993; Halford et al., 1998) stated that analogical reasoning may depend on memory capacity, we also collected data on children's memory capacity prior to the study. These data provided a means of assessing the role memory may have in the development of analogical reasoning on geometric tasks in children.

The short training procedure in the current study consisted of a standardized step by step procedure, which prompted the child to explain the reasoning behind the experimenters' correct analogical solution. Explaining correct solutions of a more knowledgeable person has been found to induce learning (Siegler, 1995; Siegler, 2002; Rittle-Johnson, 2006). The step by step procedure was based on the component processes of analogical reasoning put forward by Sternberg and Rifkin (1979): encoding, inference, mapping and application. These component processes have also been successfully used by others in training young children in analogical reasoning (e.g., Alexander et al., 1989; Resing, 1990, 2000; White & Caropreso, 1989).

Due to the microgenetic research design, in combination with several experimental conditions we used, we could examine possible changes in children's analogical performances both before and after the short training procedure, as well as differences between conditions. Furthermore, after three months we conducted a final testing to investigate whether a progress in analogical performance lasted over a more extended period of time, over both conditions in the study.

In sum, the present study aimed to answer the questions whether: 1) children's analogical performance changes due to practice alone, without explicit prompting, and whether a short training procedure adds to this effect; 2) the short training procedure has a greater effect on children showing variable, inconsistent analogical reasoning over trials than on children not showing this kind of behavior; and 3) changes in analogical reasoning either because of repeated practice alone or because of the short training procedure lasts over a period of 3 months. In addition, in an attempt to investigate the role memory capacity and inductive reasoning skills plays in the development of analogical reasoning we exploratively investigated whether children's analogical reasoning performance was related to their memory and inductive reasoning scores.

2.2 Method

Participants

Participants in this study were 36 children, 17 girls and 19 boys, from grade 1 of two elementary schools located in a midsize town in the Netherlands. From each school, eighteen children were randomly selected. For all children Dutch was the primary language in their home. Parental permission to participate was obtained for all children. At the start of testing, the children ranged in age from 5 years and 11 months to 8 years (*M*=6 years and 8 months, *SD*=4.9 months). Both genders were approximately equally represented within each condition. No child dropped out during the extended period of testing.

Material

Two pretests were used in the study: Exclusion and Memory Span. Both tests are subtests of a Dutch child intelligence test (Revisie Amsterdamse Kinder Intelligentie Test, Bleichrodt, Drenth, Zaal, & Resing, 1984). The exclusion test is a visual inductive reasoning test. It calls upon children's ability to infer rules, an ability that is assumed to be important for successful analogical reasoning. The test consists of 50 items of four abstract figures. Three figures belong together according to a rule, the child's task is to discover the rule and select the figure that does not satisfy the rule. The test served grouping purposes, but was also used to investigate whether analogical reasoning was related to inductive reasoning skills. The memory span test measures children's visual memory capacity. The testing material consists of two small booklets and two sets of small blocks with pictures. One set measures concrete visual memory and contains pictures like a fish and a flower. The other set measures abstract visual memory and contains abstract pictures with undefined forms. The pictures in the booklet are given in a certain order, which the child needs to remember and reproduce with the blocks. The amount of pictures increases steadily, making it harder to remember and reproduce the sequence. The test was used to examine whether analogical reasoning was related to memory capacity.

Testing material consisted of five parallel sets of open-ended paper and pencil geometric analogy tasks of the type A:B::C:D. Each of the five sets contained 20 items of various levels of difficulty. The original set of items represented a selection of 20 items from a highly homogeneous scale of 36 items created by Hosenfeld, Van den Boom and Resing (1997). These items were constructed out of six basic geometrical shapes – circles, squares, triangles, pentagons, hexagons, and ellipses – and five possible transformations – adding an element, changing size, halving, doubling, and changing position (Hosenfeld, Van den Boom, et al., 1997; Mulholland, Pellegrino, & Glaser, 1980). Earlier research (Mulholland et al., 1980) showed that the number of elements and transformations the item contained could satisfactorily predict its level of difficulty. However, it should be noted that although the difficult items contained more information than the easier ones, they could be reduced to smaller sets of information and consequently be solved in small steps. In this way, the amount of information that had to be processed in parallel remained small (Hosenfeld, Van der Maas, et al., 1997a). Some examples of items of various difficulty levels used in the current study are displayed in Appendix 2A.

Because of the repeated testings required in the current study, we developed 4 additional tests with parallel test items. The parallel items contained different geometric shapes, but were constructed according to comparable construction rules as were the items in the original set. The five sets were therefore supposed to be highly comparable. Each set of 20 analogical items was presented in a separate booklet. The order of presentation of difficult and easy items in each set was mixed, but remained the same over participants and sessions. Every analogical item was printed on a separate sheet of paper and presented in an open-ended format, which gave children the opportunity to come up with their own solution. Children had to draw their solution with a pencil in the last, empty box.

Additionally, a set of 6 analogical items of various difficulty levels was used during the short training procedure. These training items were constructed so that all of the five possible transformations were presented at least once.

Design

One week before the experiment started, children were pretested on the Exclusion and Memory Span tests. They were randomly allocated to either a trained or a not-trained condition based on blocked scores on the exclusion test. As can be seen in Table 1, children in both conditions were presented with the analogical reasoning tasks at weekly intervals over a period of 5 consecutive weeks. During test sessions 1 and 2 children in both conditions were administered a set of 20 geometrical analogies without any instruction or feedback concerning the correctness of their responses. During the training session, a short 15- minute-training in analogical reasoning was delivered to the children in the trained condition, while the not-trained children were presented with the same tasks, but without explicit prompting or any instructions. During test sessions 3 and 4, all children were again given a set of 20 geometrical analogies without any instructions or feedback. In addition, three months after test session 4 all children—trained and not-trained—were given a follow-up test during which they were presented again with a set 20 geometrical analogies without explicit prompting or instructions.

Table 1. Research design

Condition	Pretests: exclusion memory span	Test session 1	Test session 2	Training session[1]	Test session 3	Test session 4	Follow-up test session[2]
Trained	x	x	x	x	x	x	x
Not-trained	x	x	x	-	x	x	x

Note: [1]During the Training session, children in the not-trained condition needed to solve the same analogical items as children in the trained condition, but without receiving any instruction or feedback.
[2]Follow-up test session was administered after a period of 3 months.

General procedure

Children were tested individually. Testing took place in a separate room in the child's own school during weekly sessions lasting approximately 15–20 minutes each. The testing procedure was basically the same for both trained and not-trained conditions, during all, but the training session. Children were presented with the booklets with the geometric analogy items. The six basic geometric shapes were displayed on the cover sheet of each booklet. At the beginning of each test session, the instructor named each geometric figure in a way that the child could understand, and asked the child to copy it underneath the corresponding figure printed on the sheet. This procedure served two purposes. It gave the child the opportunity to get familiar with the testing material prior to the test. In addition, it allowed the experimenter to observe how a child drew a particular figure. This served the purpose of controlling for drawing ability, because it allowed the experimenter to take possible difficulties with drawing into account.

Subsequently, the analogy items were presented one by one with a minimum of instruction; the child was merely told that this was a kind of 'puzzle' with four boxes, the first three containing figures (the experimenter pointed to the A, B, and C boxes), but not the fourth one (the experimenter pointed to the empty D box). The child was then asked to draw what needed to be drawn in the fourth, empty box in order to solve the 'puzzle'. Then the child was given the opportunity to draw his own solution to the problem, and asked to verbally explain his way of solving the 'puzzle'.

Both the overt solution drawn on the paper and the verbal explanation provided by the child were recorded on video and analyzed afterwards. In order to ensure that the child would not just solve the analogy items over sessions on the basis of mere recognition, items consisting of the same level of difficulty but containing different geometrical shapes, were alternately administered.

Training procedure

During a short training session of approximately 15 minutes, children were given similar analogical items as they received during the test sessions. This time however, children in the trained condition were given a short standardized training procedure in which they were step by step prompted to explain the way they thought that the experimenter had found the correct solution to the so-called 'puzzle'.

First, they were presented with an analogy item of medium difficulty. They were given comparable instructions as they were given before during the test sessions. Then, they were told that the experimenter would help them this time and show them the correct solution after they finished their drawing. When the child completed the first analogy item, the experimenter revealed the correct solution and gave feedback concerning the correctness of the child's own solution. Subsequently, regardless of the correctness of the child's solution, the child was asked to explain how he thought that the experimenter had arrived at his solution. Prompting children to explain the correct solutions of someone more experienced has been shown to improve subsequent learning even more than self-explanations of their own solutions or corrective feedback (Siegler, 1995, 2002; Rittle-Johnson, 2006). Children who subsequently put forward a correct analogical explanation were still given all the steps of the analogical reasoning process in order to avoid a disadvantage for the more advanced children when new, or more difficult items were presented.

However, these children were not asked any more questions about the analogy for which they gave a correct analogical explanation. Children who put forward incorrect reasoning or partly incorrect reasoning, were given the necessary step by step questions, prompting them to correct analogical reasoning. These questions were based on the component processes put forward in studies by Sternberg and Rifkin (1979) and Resing (1990, 2000): encoding, inference, mapping and application (see Appendix 2B).

After this procedure for the first item, children were presented with a second item, which was easier than the one they just solved. Here they first had to explain what they were going to do and why, before they were allowed to draw. If necessary, they were systematically helped towards the right analogical answer, using the above mentioned procedure. In this way they could practice out loud what they had just learned and could be corrected if they would fall back into any incorrect old pattern of solving the analogical item. The third training item was more difficult again and children were taken through the same procedure as they were during the first training item. The fourth training item was about as difficult as the third one, but followed the same procedure as the second training item. The fifth training item was the most difficult kind of analogical item they would encounter during testing. This item contained three elements and five different transformations. The procedure was equal to that for the first training item. The sixth and last training item was once again an easier item in order not to discourage children who found the fifth item too difficult. The procedure followed for the sixth training item was the same as for the first one.

Scoring

Test items were scored on the basis of a combination of both children's drawing and their verbal explanations. Some children sometimes experienced difficulties with drawing the geometrical shapes. However, this did not cause any problems, because the experimenter had seen how the child had drawn all of the figures on the cover sheet and therefore usually knew what the child meant by a particular drawing. Whenever she doubted, she asked the child to point out and explain which figure(s) he meant by that (e.g., can you point out or tell me which figure this one is supposed to be?).

The scoring-system that we used was adapted from a scoring-system used by Hosenfeld, Van der Maas, et al. (1997b) for comparable geometric analogy tasks and earlier by Resing (1990) for verbal analogies. This scoring-system consisted of 4 types of solutions: explicit correct analogical (Category 1); implicit correct analogical (Category 2); incomplete analogical (Category 3); and non-analogical, associative (Category 4). Explicit and implicit solutions (Categories 1 and 2) are both considered correct analogical solutions. However, an explicit solution indicates that the child has drawn and explicitly stated verbally all the transformations the analogy item contained, while an implicit solution indicates that the drawing looked correct, but the child has not explicitly stated all the transformations that the analogy item contained. An incomplete analogical solution indicates that analogical reasoning is present but only partially, for either one or more, but not all, of the transformations the item contained was drawn and mentioned verbally. The non-analogical, associative type of solution indicates that the solution was produced by an association strategy instead of analogical reasoning. Solutions scored in this category are for example: a copy of elements from the A, B or C terms; a complete or partial copy of the A, B or C term; a copy of A, B or C with horizontal or vertical position change. Some examples of children's descriptions of their own reasoning are displayed in Table 2.

Inter-rater reliability
All data were coded by the second author. To estimate coding reliability, data for the first two weeks (40%) were coded by the first author who was blind to the child's condition. Inter-rater agreement was 97%, indicating that the data were scored reliably.

2.3 Results

Before investigating the research questions, we examined children's initial level of inductive reasoning. The result of a one-way ANOVA, with the independent variable being condition with two levels—not trained and trained—and the dependent variable being children's score on the inductive reasoning Exclusion test, showed no significant effect for condition. This finding indicates that the two conditions did not have different levels of inductive reasoning prior to the first test session. The first research question concerned whether children's analogical performance changed due to practice alone, without explicit prompting, and whether a short training procedure added to this effect. In order to answer this question, we analyzed the data at both the group level and the individual level. The analyses at the group level were expected to provide general information on changes in the analogical performances of the two experimental conditions. The analyses at the individual level were expected to provide more detailed information on how changes occurred.

Analyses at the group level
First, it was important to investigate whether the two conditions had comparable levels of analogical reasoning at the start. A one-way ANOVA was conducted, with the independent variable being condition with two levels – not trained and trained – and the dependent variable being the number of correct analogical – explicit and implicit – solutions on test session 1. We included both Category 1 and Category 2 types of solutions in this analysis because these two types of solutions are both considered correct analogical solutions. An overview of the mean number of correct analogical solutions per session and condition is displayed in Table 3. The results showed no significant effect for condition, indicating that children in the two conditions did not differ with respect to their levels of analogical reasoning at the start.

Next, we conducted a one within (Session: test sessions 1–4) and one between (Condition: not trained and trained) repeated-measures ANOVA to investigate whether the two conditions changed their use of analogical strategies over time. The dependent variable in the analysis was the number of correct analogical—explicit and implicit—solutions (Category 1 and 2) for each test session (see Table 3). The results showed a statistically significant session

Table 2. Examples of children's descriptions of their own reasoning

Category	Example	Description
Non-analogical	1	Here you can see a hexagon (points to C). Therefore I draw the same in here (points to D) [child copied the C-term]
	2	Here I see a square and there I see a pentagon (points to the figures in A). I draw the same in here (points to the figures in D) [child copied the A-term]
	3	A circle with a pentagon in it (points to C). I did the same here (points to D) [child copied the C-term]
Incomplete	1	Here circle (points to A) and half circle (points to B). There hexagon (points to C) and a bowl (points to D) [child draw a half hexagon; lower half]
	2	Look, here (points to B) you see a square with a star in it and there (points to A) you can see a square with no star. And there (points to the pentagons in B) you can see 2, and there (points to pentagon in A) you see only one. Here (points to oval in C) is also only one. Therefore, I have 2 of them (points to 2 ovals in D) [child draw the correct transformations, but no star in the triangle]
	3	Look, here is an oval in a hexagon (points to the figures A). And there (points to the figures in B), there are two of those things in a big oval. That is why I have drawn 2 circles in a big pentagon [child draw only one of the transformations]
Implicit	1	Circle (points to A), half circle, half circle (points to B). There is a hexagon (points to C). Half hexagon, half hexagon (points to D) [child draw the correct figures]
	2	Square, pentagon (points to the figures in A). Square, star, pentagon, pentagon (points to the figures in B). Triangle, oval (points to the figures C). therefore, triangle, oval, oval [Child draw the correct figures; with a star in the triangle]
	3	Here I see a hexagon with an oval in it, and there a triangle (points to the figures in A). And here I see another triangle, but there is an arrow in it (points to B). And here I also see 2 small hexagons with a big oval around it (points to B). Then I did the same with these figures (points to C) and got this (points to D) [Child draw the correct figures]
Explicit	1	Here is a circle (points to A), and there are two half circles (points to the figures in B). And there (points to C) I can see a hexagon. Therefore, I did the same here and draw 2 of these (points to the 2 halves of the hexagon drawn in D) [Child draw the correct figures]
	2	Here is a square and a pentagon (points to the figures in A). Here is also a square, but with a star in it (points to B). And there are also two pentagons. Here is a triangle and there one oval (points to the figures in C) and look there is no star in it (points to the triangle in C). That is why I draw a triangle with a star in it here, and there 2 ovals (points to the figures in D) [Child draw the correct figures]
	3	An oval with a hexagon around it, and a triangle (points to the figures in A). Circle with a pentagon and a square (points to the figures in C). Here is an arrow in the triangle and a big oval around the two hexagons (points to the figures in B). That is why (points to D) square with an arrow in it here, and pentagon with 2 circles in it there [Child draw the correct figures]

Note: Examples 1, 2 and 3 refers to the examples in Appendix 2A.

effect, Wilks' λ=.33, F (3, 32)=21.28, p<.001, partial η^2=.67, but, more important, there was also a statistically significant interaction effect between session and condition, λ=.51, F (3, 32)=10.44, p<.001, partial η^2 =.50.

Table 3. Means and standard deviations of the number of analogical responses per condition and session

Condition	Session			
	1	2	3	4
Not trained				
M	3.17	4.83	5.17	5.06
(SD)	(4.73)	(6.46)	(6.95)	(6.70)
Trained				
M	3.11	5.78	12.06	12.00
(SD)	(3.41)	(6.39)	(6.22)	(6.22)

The results of follow-up repeated contrasts evaluating the session effect revealed that there was a difference in the number of analogical solutions between test sessions 1 and 2, and between test sessions 2 and 3, F (1, 34)=17.85, p<.001, partial η^2 =.34 and F (1, 34)=28.85, p<.001, partial η^2 =.46, respectively. As can be seen in Table 3, the means for the second test session were higher relative to the means for the first test session, and the means for the third test session were higher relative to the means for the second test session, indicating an improvement in analogical solutions from test sessions 1 to 3. No significant difference was found between test sessions 3 and 4, indicating that children's analogical performance stabilized from test sessions 3 to 4.

Investigation of the session by condition interaction effect using repeated contrasts follow-up analyses, revealed that there was a difference among conditions between test sessions 2 and 3, F (1, 34)=23.32, p<.001, partial η^2=.41. The trained children showed greater improvement in their use of analogical strategies between test sessions 2 and 3 relative to the not-trained children, who hardly improved their analogical performance between these two test sessions ($ES_{trained/not\text{-}trained}$=.96)[1], as can be seen in Figure 1. These findings led us to conclude that practice alone led to an increase in the use of analogical strategies between test sessions 1 and 2. However, the short training procedure led to an improvement in analogical reasoning between test sessions 2 and 3 over and above that of practice alone.

Because averaging data over strategies may distort conclusions about several aspects of children's performance (Siegler, 1987), we also examined the performances of the two conditions generated by each strategy separately. On this account, we conducted 4 separate one within (Session: test sessions 1–4) and one between (Condition: not trained and trained) repeated-measures ANOVAs. The dependent variables in the separate analyses were the number of explicit correct analogical (category 1), implicit correct analogical (category 2), incomplete analogical (category 3) and non-analogical, associative (category 4) solutions on each of the 4 test sessions. The course of each strategy over test sessions can be seen in Figure 2.

1 $ES_{trained/not\text{-}trained}$ represents the standardized mean difference (d) between the scores of test sessions 3 (after the training) and 2 (before the training) for the trained group minus the standardized mean difference (d) between the scores of test sessions 3 and 2 for the not-trained group.

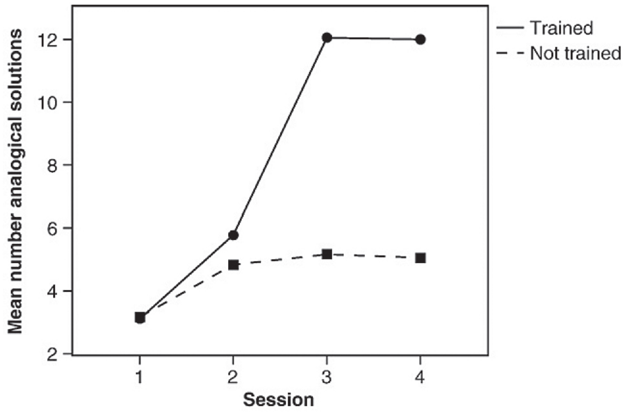

Figure 1. Changes in the number of correct analogical solutions by condition.

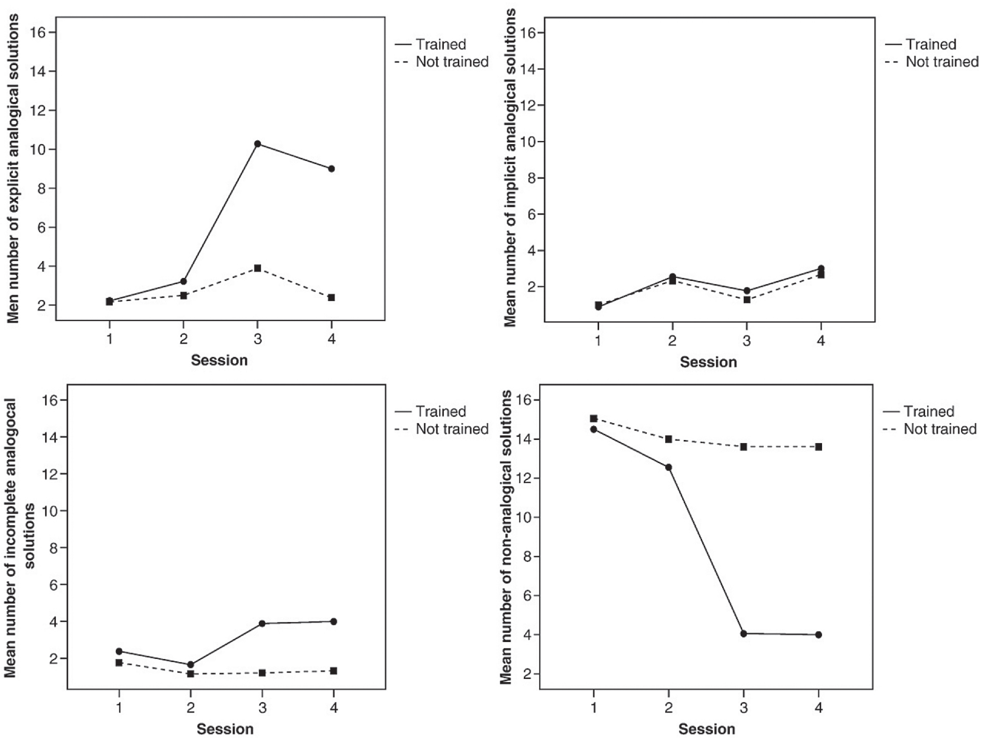

Figure 2. Changes in the number of explicit analogical, implicit analogical, incomplete analogical, and non-analogical solutions by condition and session.

Explicit analogical solutions

The results of the first ANOVA, the analysis on the number of explicit correct analogical solutions, showed a statistically significant effect for both session and the interaction between session and condition, Wilks' λ=.46, F (3, 32)=12.30, p<.001, partial η^2 =.54 and Wilks' λ=.60, F (3, 32)=7.04, p=.001, partial η^2 =.54, respectively. Evaluation of the session effect with repeated contrast analyses showed that there was a difference among the means for test sessions 2 and 3 and for test sessions 3 and 4, F (1, 34)=31.57, p<.001, partial η^2 =.48 and F (1, 34)=6.94, p=.013, partial η^2 =.17, respectively. The difference between test sessions 1 and 2 was almost significant, F (1, 34)=3.63, p=.065, partial η^2 =.10. Investigation of the session by condition interaction effect revealed a difference among conditions only between test sessions 2 and 3, F (1, 34)= 14.22, p=.001, partial η^2 =.30. As can be seen in Figure 2, these results suggest that children, regardless of condition, used the explicit analogical strategy slightly more frequently from test sessions 1 to 2. From tests sessions 2 to 3 both conditions further improved their use of explicit solutions, but the improvement was considerably greater for the trained condition. From test sessions 3 to 4 the two conditions showed a slight decrease in their use of the explicit analogical strategy.

Implicit analogical solutions

The results for the second ANOVA, the analysis on the number of implicit correct analogical solutions, also showed a statistically significant effect for session, Wilks' λ=.75, F (3, 32)=3.63, p=.023, partial η^2=.25, but not for the interaction between session and condition. Evaluation of the session effect using repeated contrast analyses indicated that, regardless of condition, there was a statistically significant difference in the number of implicit analogical solutions between test sessions 1 and 2, and between test sessions 3 and 4, F (1, 34)=7.65, p=.009, partial η^2=.18 and F (1, 34)=6.66, p=.014, partial η^2=.16, respectively. These results suggest that the use of the implicit analogical strategy improved through practice alone; the short training procedure had little additional effect on its use since both conditions changed their number of implicit analogical solutions approximately the same during the period of the study.

Incomplete analogical solutions

The results of the ANOVA on the number of incomplete analogical solutions showed a statistically significant effect for session only, Wilks' λ=.72, F (3, 32)=4.22, p=.013, partial η^2=.39. The results of repeated contrast analyses evaluating this session effect revealed that the effect was due to an improvement in the number of incomplete analogical solutions between test sessions 2 and 3, F (1, 34)=7.02, p=.012, partial η^2 =.17. As can be seen in Figure 2, the trained condition showed more frequently incomplete solutions than the not trained condition, particularly during test sessions 3 and 4. Further inspection of the data revealed that with this progression, children in the trained condition decreased their use of non-analogical, associative strategies even more.

Non-analogical solutions

The results of the ANOVA on the number of non-analogical solutions revealed a statistically significant effect for session as well as for the interaction between session and condition, Wilks' λ=.41, F (3, 32)=15.19, p<.001, partial η^2=.59 and Wilks' λ=56, F (3, 32)=8.35, p=.001, partial η^2=.44, respectively. Evaluation of the session effect showed that there was a difference in the use of non-analogical strategies between test sessions 1 and 2 and between test sessions 2 and 3, but not between test sessions 3 and 4, F (1, 34)=9.63, p=.004, partial η^2=.22 and F (1, 34)= 23.87, p<.001, partial η^2=.41, respectively. The results of follow-up analyses evaluating the session by condition interaction effect revealed that the effect was due to a difference among conditions between test sessions 2 and 3 only, F (1, 34)=19.88, p<.001, partial η^2=.37. This result indicates that practice alone led to a rather continuous decrease in the use of non-analogical strategies from test sessions 1 to 3, as can be seen in Figure 2. However, the short training procedure decreased the use of these inappropriate, non-analogical strategies even more. After the third session the use of non-analogical strategies stabilized.

Analyses at the individual level

In order to gain more detailed information on the process of change in the use of analogical strategies, we also investigated the data on analogical reasoning at the individual level. We were particularly interested in whether the data for the individual children of both conditions revealed specific patterns of change over the 4 test sessions. We therefore observed for each individual child the number of correct analogical – implicit and explicit – responses on each of the 4 test sessions. Next, we investigated change in the distributions of their response categories from test sessions 1 to 4. If a child progressed 15% (3 out of the 20 items) or more from one test session to another, this was considered an improvement in analogical reasoning. Various patterns of improvement in analogical reasoning were then identified within the two conditions. Children with a similar pattern of improvement were grouped together. These subgroups of children took varying routes in the acquisition of analogical strategies to solve geometric tasks (see Table 4).

As can be seen in Table 4, within the not-trained condition, three subgroups of children with varying patterns of change in analogical reasoning were identified. The first subgroup consisted of 10 children who made no progression at all during the period of the study. These children practically only used non-analogical strategies across the 4 test sessions. A second subgroup consisted of 7 children who progressed from test sessions 1 to 2 only. Finally, there was 1 child who made no progression because he scored high from the beginning.

Table 4 also displays that within the trained condition 4 subgroups of children with varying patterns of change in the use of analogical strategies were identified. The first subgroup consisted of 2 children who, despite the short training procedure, only used inadequate, non-analogical strategies during the 4 test sessions. The second subgroup consisted of 3 children who improved considerably through practice from test sessions 1 to 2, but did not progress any further after the short training procedure. The third subgroup consisted of 9 children who made no progression from test sessions 1 to 2. However, after the short training procedure this subgroup made considerable progression during the third test session. The fourth subgroup consisted of 4 children who progressed from test sessions 1 to 2, and after the short training procedure made additional progress during test session 3.

Table 4. Number of children per subgroup and condition

Condition [1]	No improvement/ low scores	Improvement between sessions 1–2[2]	Improvement between sessions 2–3[3]	Improvement between sessions 1–2–3[4]	No improvement/ high scores
Not trained	10	7	-	-	1
Trained	2	3	9	4	-

Note: [1]N=18 per condition, [2]Improvement due to practice alone, [3]Improvement due to training alone, [4]Improvement due to practice (1–2) and training (2–3).

2

Inter- and intra-individual variability in analogical strategy changes

Next, it was important to investigate the distributions of the various response categories of the individual children within each of the subgroups more closely in order to say something about the pattern of changes in the use of analogical strategies within individuals. For the not-trained condition only the distribution of the response categories of the second subgroup was examined, because the children in the other two subgroups made no improvement. For the trained condition, we examined only the distributions of response categories of subgroups 3 and 4, since the first subgroup made no improvement and the second subgroup only consisted of 3 children of which two children reached near maximum score during test sessions 2 to 4.

Not-trained condition

The distributions of the response categories of the individual children in the second subgroup (increases from test sessions 1 to 2) of the not-trained condition are displayed in Figure 3. As can be seen in this figure, there was much within-child variability within this subgroup. Moreover, the children who relatively often showed incomplete analogical responses during

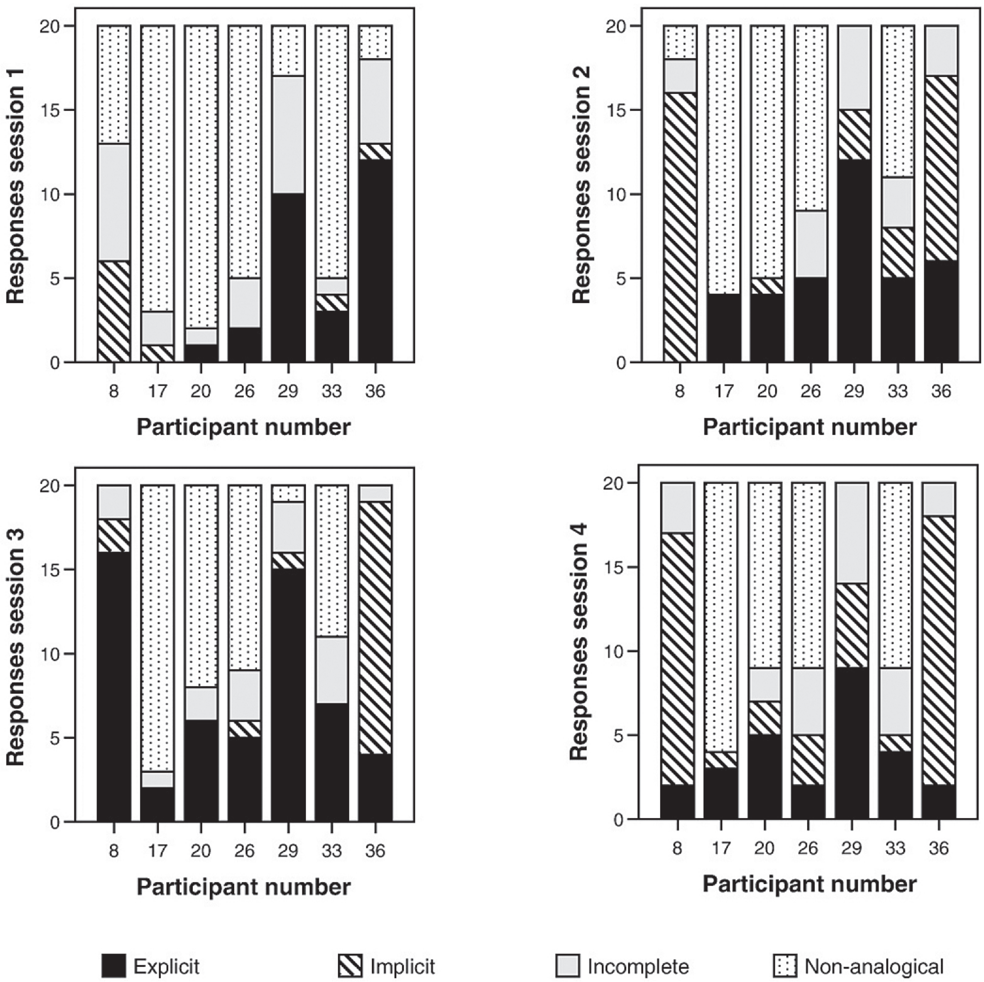

Figure 3. Number of responses per category, session and child of subgroup 2 of the not-trained condition.

the first test session, made the most improvement in test session 2. This observation suggests that the earlier described practice effect between these two test sessions was mostly due to a progression from incomplete to complete – either explicit or implicit – analogical solutions.

Trained condition

The distributions of the response categories of the individual children in the third subgroup (increases from test session 2 to 3) of the trained condition are displayed in Figure 4. This figure reveals that the 5 children (6, 12, 13, 22, and 31) who showed some analogical reasoning in the first 2 test sessions showed a considerable increase in analogical – either complete or incomplete – solutions from the second to the third test session. After test session 3 their response patterns stabilized. However, the remaining 4 children (3, 4, 24 and

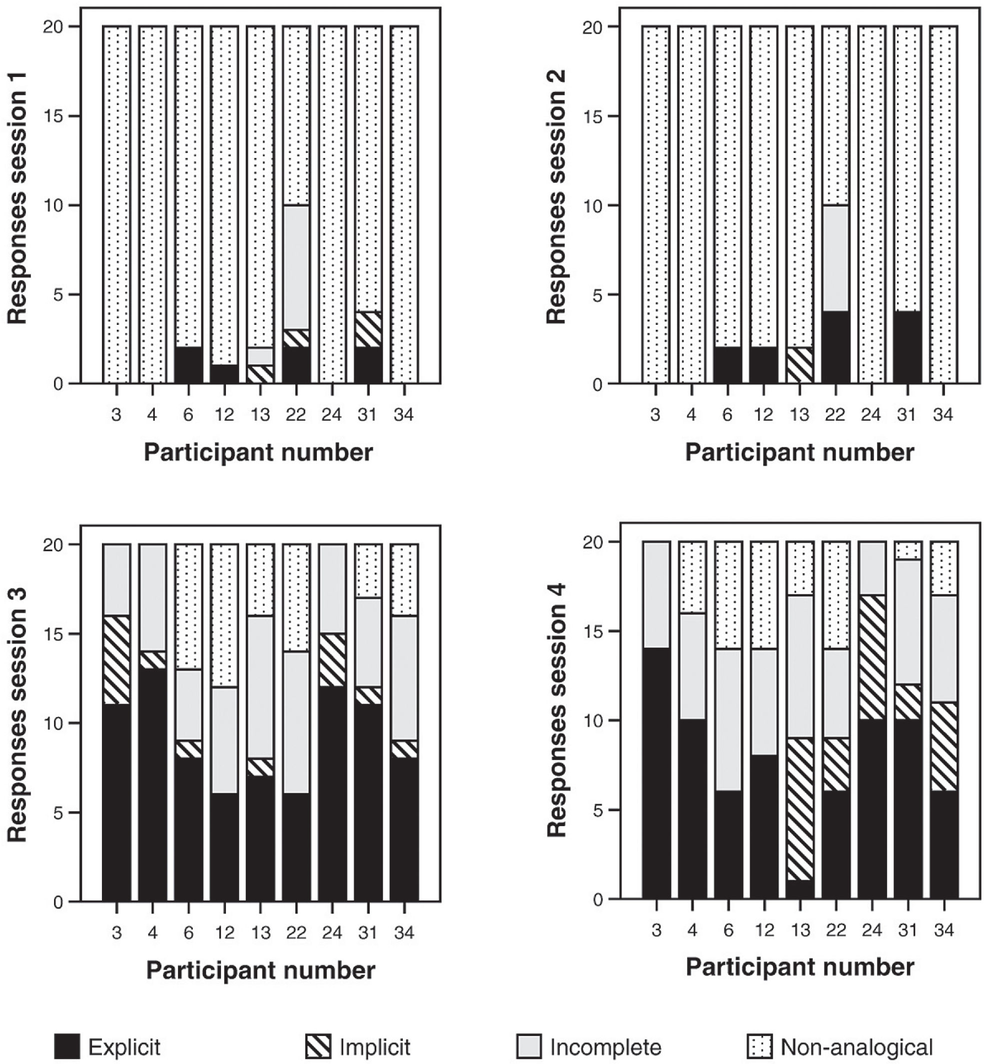

Figure 4. Number of responses per category, session and child of subgroup 3 of the trained condition.

34) in this subgroup went from completely non-analogical to approximately 15 complete plus 5 incomplete analogical solutions. A rather rapid change in analogical thinking was thus made at one time. Therefore it can be concluded that the short training procedure had a different effect on the process of change in the use of analogical strategies in children at this age.

The distributions of the response categories of the individual children in the fourth subgroup (increases from test session 1 to 2 and test sessions 2 to 3) of the trained condition are displayed in Figure 5. This figure shows that all children in the fourth subgroup increased in all analogical – either complete or incomplete – response categories from test sessions 1 to 2.

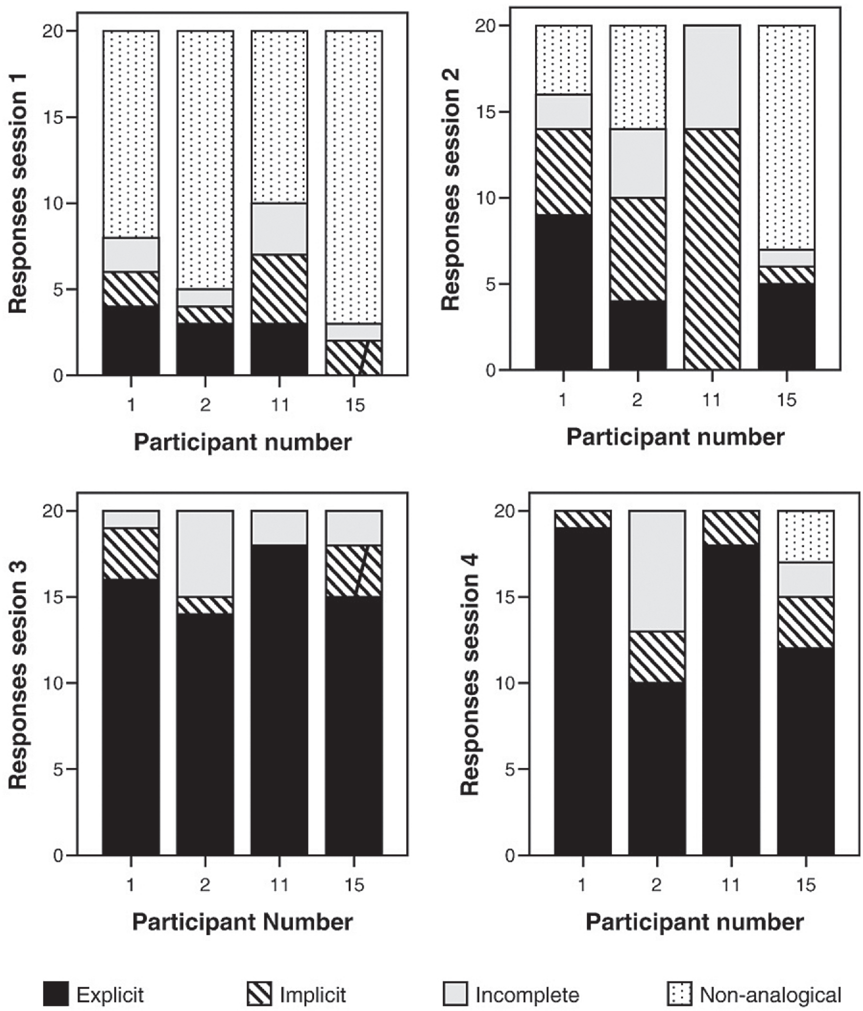

Figure 5. Number of responses per category, session and child of subgroup 4 of the trained condition.

This improvement can be attributed to practice. From test sessions 2 to 3 they particularly increased their number of explicit analogical solutions. Apparently, the short training procedure led these children to become more explicitly analogical. It can also be seen that these children did not give non-analogical responses any longer during this third test session; they gave incomplete analogical responses instead. During the fourth test session, the facilitating effect of the short training procedure continued for 3 of the 4 children.

Because the age range of the participants seems a bit wide, we conducted several Mann-Whitney *U* tests to evaluate whether the observed differences in response patterns over sessions among the various subgroups were due to age. For the not-trained condition, we compared subgroups 1 versus 2 with respect to age. For the trained condition, we compared the ages of subgroups 1 versus 2, subgroups 1+2 versus 3, subgroups 3 versus 4, and within subgroup 3 for children who showed some analogical reasoning on the test sessions 1 and 2 versus children who showed no analogical reasoning on the first two test sessions. We did not find any significant difference among the various subgroups with respect to age, indicating that the observed differences in responding over time among the various subgroups were not due to age.

Next, we conducted several Mann Whitney *U* tests to examine possible differences among the subgroups with respect to inductive reasoning and memory (concrete and abstract) capacity. Results of all comparisons were not significant, indicating that the observed differences between the various subgroups in responding over time were not due to children's inductive reasoning or memory capacity either.

Change in inconsistent analogical reasoners

Next, we examined the question whether the short training procedure had a greater effect on children showing variable, inconsistent analogical reasoning over trials than in children not showing this kind of behavior. To answer this question we divided the trained children, based on their scores in test session 2 (before the training), into three groups: non /weak-analogical reasoners, children who had less than 25% of the items correct; variable, inconsistent analogical reasoners, children who had 25%–75% of the items correct; and strong analogical reasoners, children who had more than 75% of the items correct. Then, we conducted an ANCOVA, with the dependent variable being the number of correct analogical responses (category 1 and 2) in test session 3 (after the training) and the covariate being the number of correct analogical responses (category 1 and 2) in session 2 (before the training). The independent variable consisted of two levels: non/weak-analogical reasoners (N=11) and variable analogical reasoners (N=5). The third group (strong analogical reasoners) was not included in this analysis since these children could not improve much more. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, F (1, 12)=.02, MSE=26.40, p=.89, partial η^2=.00. The results of the ANCOVA were non-significant, indicating that the short training procedure did not have a greater effect on children showing variable, inconsistent analogical reasoning over trials than on children not showing this kind of behavior.

Duration of the effects

The next question related to whether the improvement in the use of analogical strategies observed in the microgenetic study lasted over a longer period of time. For the purpose of this issue all children – not trained and trained – were seen in a follow-up test session 3 month after test session 4. A one within (Session: test sessions 4 and follow-up test session) and one between (Condition: not trained and trained) repeated-measures ANOVA, with the dependent variable being the sum of correct analogical – explicit and implicit – responses for each session, was conducted. The results of the analysis associated with the within-subject effects showed a statistically significant effect for session, Wilks' λ=.82, F (1, 34)=7.39, p=.01, partial η^2=.18, but no interaction effect. The means of both the trained and the not-trained condition were higher on the follow-up test session (M=13.06, SD=6.10 and M=6.06, SD=6.81, respectively) than on test session 4 (M=12.00, SD=6.22 and M=5.06, SD=6.70, respectively), indicating an increase in the use of analogical strategies over a period of 3 months for both conditions. Since there was no interaction effect, it can be concluded that children in both conditions improved their analogical performance in a similar manner. The results of the analysis associated with the between subject effects showed statistically significant differences in the use of analogical strategies among the two conditions, F (1, 34)=10.80, p=.002, partial η^2=.24. Observation of the means revealed that the trained children (M=12.53, Std. Error=1.5) gave considerably more analogical responses than the not-trained children (M=5.56, Std. Error=1.5) on the two sessions combined.

Relation between variables

The next question concerned whether children's analogical reasoning performance was related to their memory or inductive reasoning scores. We computed correlational coefficients among the analogical reasoning measure (represented by the number of correct analogical explicit and implicit solutions for the first—two test sessions before the training—and second—two test sessions after the training—half of sessions) and the inductive reasoning and memory (concrete and abstract) measures. The correlational coefficients were computed for the two conditions separately to eliminate conditions from the relations, allowing us to make comparisons across conditions. The results showed for the two conditions non-significant correlations among the inductive reasoning and analogical reasoning scores on both halves of sessions. The correlations among the concrete memory and analogical reasoning scores on the two halves of sessions were also non-significant for the two conditions. However, for the relation between the abstract memory and analogical reasoning scores, we found statistically significant correlations for the trained children on the second half of sessions ($r_{pearson}$=.678, p=.02). These results suggest that the trained children who were scoring high on the abstract memory measure also tended to score high on the analogical reasoning measure during the two test sessions after the short training procedure.

2.4 Discussion

The main purpose of this study was to gain insight into the nature of young children's analogical reasoning ability by investigating whether the analogical performance on geometric tasks of 6–8 year-old first-grade children changed due to repeated practice alone, without explicit prompting, and whether a short training procedure that provided children with some explicit modeling and feedback added to this effect. As stated in the introduction, several studies on children's analogical reasoning ability have been conducted in the past, but only one study (Tunteler & Resing, 2007a) has focused on a comparison of the path of natural, unprompted changes in analogical reasoning performance with that of changes induced by a short training procedure. The present study differs from the Tunteler and Resing (2007a) study in that it focused on geometric tasks, rather than problem analogy tasks. In addition, the short training procedure in our study was given between test session 2 and 3, which allowed us to investigate changes in children's analogical performances both before and after the short training procedure.

The results of our microgenetic study revealed new insights into the nature of changes in analogical reasoning on geometric analogical tasks in grade 1 level children. One of our findings was that the analogical performances of children of this grade level changed spontaneously as a result of practice alone, without any helpful instruction to the task or prompting. 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 on geometric tasks then suggests that analogical reasoning skills must have been already present, though in a more rudimentary form, in the repertoire of children of this age and that the opportunity to practice accelerated it's spontaneous use. This result is consistent with earlier findings of Tunteler and Resing (2002, 2007a,b), who demonstrated that 4- to 8-year-old children spontaneously improved their use of analogical strategies to solve problem analogy tasks after practice experiences. Similar results have also emerged from studies that have examined young children's knowledge of geometric transformations in the plane; Logo experiences have been shown to increase young children's awareness of geometric figures and their ability to communicate about spatial ideas (see Clements & Battista, 1992; Clements, Battista, Sarama & Swaminathan, 1997).

Another finding of the study is that spontaneous, unprompted changes in analogical reasoning performance was most prominent between test sessions 1 and 2; the analogical performance of the not-trained children remained rather stable during test sessions 3 and 4. In a study by Alexander et al. (1989), similar changes in geometric analogical reasoning were found in preschoolers and kindergartners. The authors suggested that this improvement was due to familiarity with the test-items, but they gave the children in their study extensive instructions to the tasks. As instructions may be seen as a form of training, one may object that the increase in analogical performance observed in the Alexander et al. study may also be attributed to the instructions repeatedly given to the children. In our study, the geometrical analogy tasks were given with no instruction other than that the tasks were like a 'puzzle'; neither was any feedback given. Therefore, our results clearly demonstrate that young children can indeed change their knowledge and strategy for analogy by experience alone, confirming that it is well within their developmental range of growth to grasp analogical ideas related to geometric shapes.

Our results were interesting in the light of other microgenetic studies, which tended to reveal that changes in a cognitive competency is a result of a changing distribution of various strategies of varying adequacy (Kuhn, 1995; Siegler, 2006). In this study, changes in the distribution of the various response categories were analyzed at both the group and the individual level. Analyses at the group level indicated that the natural, unprompted increase in analogical performance observed between test sessions 1 and 2 was greatly due to an increase in implicit correct analogical solutions. More in-depth analysis of the patterns of change in the use of analogical strategies within individuals of the not-trained condition added to this finding that approximately half of the not-trained children did not progress during the study period, while another half of the children did. The distributions of the response categories of this latter subgroup showed considerable variability in task performance within individuals, referring to diverse and variable strategy use within as well as across trials. This finding is consistent with findings of earlier studies with problem analogy tasks (Tunteler & Resing, 2002, 2007a,b). The children who relatively often showed incomplete analogical responses during the first test session, made the most improvement during test session 2, suggesting that the observed increase in analogical performance was mostly due to a progression from incomplete to complete – either implicit or (to a less extent) explicit – analogical solutions. Although not the focus of the study, this finding seems to provide evidence for the propositions that children make unconscious discoveries of analogical strategies, which subsequently becomes conscious analogical reasoning. This observation confirms research from Siegler and Stern (1998) who found similar results with children in a study on strategy discovery on an arithmetic task. However, it should be noted that the not-trained children in our study were not given any instruction or feedback with respect to their solutions. They may therefore have executed an analogical strategy at a conscious level, but did not report it because they did not know that it was better to do so. Therefore, further research is recommended to investigate this issue in more detail.

With respect to the paths of change of the trained children, the results showed that the short training procedure caused an increase in the use of analogical strategies on geometric tasks that could not be explained by practice alone. Examination of the performance of this group of children generated by each strategy separately revealed that the short training procedure particularly had an effect on children's use of explicit correct analogical strategies and, although to a lesser extent, on their use of incomplete analogical strategies. Our findings suggest that children after the short training procedure mastered their correct responses mostly explicitly and when they were not up to a complete analogical solution, they solved the item partly analogically without entirely reverting back to an associative response. These changes in the use of analogical strategies observed in the trained group tended to go together with a rather rapid decrease in the use of non-analogical, associative responses, while a rather continuous decrease in the use of this non-analogical strategy was observed in the not-trained group.

More in-depth analysis of the patterns of changes within individuals of the trained condition revealed a varied picture. Within this condition, there were 2 children who remained consistent non-analogical, regardless of the short training procedure, and 3 children who spontaneously improved their analogical reasoning through practice alone. Another 4 children improved through practice and also through the short training procedure, after which they particularly became more explicitly. These children showed a gradual change in their distribution of correct analogical responses over time, confirming the microgenetic picture of learning proposed by Kuhn (1995). The remaining 9 children made a relatively larger change towards analogical reasoning after the short training procedure. Surprisingly, in this subgroup, it were not the children with variation in strategies that showed the most improvement, but the children exhibiting only non-analogical strategies during the first two practice sessions. This latter group of children even went from completely associative reasoning to consistent analogical reasoning after the short training procedure, indicating a rather rapid change within one time point. These results provide evidence for 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 shows a more rapid change in this respect. They also challenge the position that analogical reasoning on geometric tasks is an age related competence which can not be induced by training in children only showing non-analogical, associative reasoning (Hosenfeld, Van der Maas, et al., 1997b). Apparently analogical reasoning was already present in the cognitive processing abilities of these young children, but needed some prompting.

Taken together, consistent with results of Tunteler and Resing (2007a) with problem analogy tasks, our results showed considerable inter and intra-individual variability in the use of analogical strategies in both not-trained and trained first-grade children. According to Siegler (2006) such intra-individual variability in strategy use has been shown to predict later learning substantially. The findings described above provide evidence for this position for the not-trained 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 practically only showing 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 did not only induce change in the analogical performances of children initially showing variable analogical reasoning, but also in children only showing non-analogical, associative reasoning during the test session prior to the training session. Moreover, analysis at the group level showed that the short training procedure did not have a greater effect on children who displayed variable analogical reasoning, defined by having 25%–75% correct analogical solutions on the test session prior to the training session, than on children not showing this kind of behavior. It should however be noted that this outcome should be interpreted with some caution, since the groups in this analysis were rather small and of unequal sizes and the age range of the participants was a bit wide. Replication of these results is therefore needed to verify and extend our results.

Another result of the study is that both the trained and not-trained children improved their analogical performances in a follow-up test session that was conducted after a retention period of 3 months after test session 4. It is not clear whether this improvement occurred as a result of our experimental procedure or because of another variable. More important however, this finding indicates that the observed progress in analogical performance lasted over a more extended period of time, over both conditions in the study. Apparently, changes in analogical reasoning obtained through experience or a short training procedure do not only persist over a period of time during which children are repeatedly given practice opportunities, as Tunteler and Resing (2007a,b) showed earlier with problem analogy tasks, but also last over a longer period of time during which children are not given these experiences. This observation then suggests that these young children had incorporated the analogical strategy within their existing set of strategies for solving geometric analogy tasks.

Finally, in an attempt to investigate the role memory capacity and inductive reasoning skills may play in the development of analogical reasoning, we investigated whether children's analogical reasoning performance was related to their memory (abstract and concrete) or inductive reasoning scores. Our results only revealed a relation between children's analogical reasoning scores and their scores on the abstract memory test for the trained children during the test sessions after the training session. The analogical items used in our studies consisted of geometric shapes of various difficulty levels. The difficult items contained more information than the easier ones, but they could be solved in small steps by reducing them to smaller sets of information. The short training procedure consisted of a standardized step by step procedure, which prompted the child to explain the reasoning behind the experimenters' correct analogical solution. We suggest that the short training procedure made children more aware of the fact that they could solve the analogical tasks in small steps, reducing the amount of information that had to be processed in parallel, allowing them to solve analogical items of increasing levels of difficulty. The finding that this relation was only found for the trained children during the test sessions after the training provides evidence for this position.

Although individual differences and variability in the acquisition of novel strategies are not unique for the area of analogical reasoning (e.g., Kuhn, 1995; Siegler, 1995, 2006), it is important to consider these issues with respect to the acquisition of analogical strategies on geometric tasks more closely in future studies. At this moment it is not clear why some of the children in our study increased their use of analogical strategies through practice, some others through training, again some others through a combination of the two, while still some others did not progress even despite of the short training procedure. One objection may be that the age range of the participants was a bit wide, and that these children therefore may have been in a different developmental range of growth with respect to analogical reasoning. Yet, it should be noted that no age differences were found among the various subgroups with different patterns of responding over time. Explanations in terms of a lack of inductive reasoning skills or memory capacity are not sufficient either, because our results showed no differences in this respect among the various subgroups.

It is also not clear why the 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 their peers who already showed some analogical reasoning prior to the short training procedure. Apparently, the absence of any partially formed strategy among these children allowed them to adopt strategies they had learned about as they tried to explain the steps taken by an interviewer as she solved the tasks. A possible explanation for this finding could therefore be that children who already solved some analogical items correctly may have improved less, because learning a completely new strategy may be easier than integrating a more advanced strategy with an old, less advanced one or replacing a less advanced strategy with a more advanced one. This observation might then indicate that correctly instructing young children from the beginning, before giving them the opportunity to practice, might prove a better way to accelerate the process of acquisition and generalization of analogical strategies in some children, because correctly instructing them from the beginning might prevent interference of less adequate or deficient analogical strategies. This result has important implications for geometry education as it clarifies how 6-8 year old children from first grade can address logical operations on spatial objects through analogies. Yet, the data here came from one experiment and the subgroups consisted of relatively small numbers of children; any conclusions drawn from these data must be treated with the necessary caution. We therefore recommend further research into young children's use of analogies on tasks involving geometric transformations.

It was clear from our data that the short training procedure had an additional effect above practice alone on a considerable number of children of this age. One may then question what factors could have led to this effect. In essence, our short training procedure consisted of modeling and a step by step procedure of prompting children to self-explain all the steps of correct analogical reasoning proposed by Sternberg and Rifkin (1979) and Resing (1990). As discussed above, the increase in analogical performance due to the short training procedure observed in this study was mostly due to an increase in explicit correct analogical responses, meaning that children not only solved the analogical item correctly, but also verbally explained correct analogical reasoning for their solutions without explicitly being told to do so. Additionally, besides the increase in complete analogical responses, there was also an increase in incomplete analogical responses after the short training, while completely associative responses were nearly extinguished. These findings certainly reveal conceptual mastery. We therefore suggest that our results confirm the prediction made by Rittle-Johnson (2006) "... that direct instruction on a correct procedure and conceptual explanation for the procedure would lead to the greatest learning and transfer if students were also prompted to self-explain" (p. 13). Yet, in this study we did not compare the effects of various types of training on analogical reasoning at this age. Therefore, future research needs to be conducted in which instruction procedures are varied in order to give a conclusive answer to the question cited above. Moreover, it would be advisable to investigate whether similar results can be obtained while instructing children of other ages and also with different types of analogical tasks.

In sum, we can conclude from our results that although repeated practice has a beneficial effect on the natural, unprompted use of analogical strategies to solve geometric tasks by first-grade children, the provision of a short training procedure that provides children with some explicit modeling and feedback adds to this effect. The short training procedure used in our study induced in 9 of the 18 children a continuation of a gradual process of change in the acquisition of analogical strategies, while in 4 others it induced a rather rapid change in analogical reasoning. Since this observation may have important implications for analogical learning in educational settings, it would be good to investigate whether teachers could obtain similar results with their children (Alexander et al., 1987) and whether children will extend their learning to other (analogical) tasks as well. Moreover, it would be interesting to extend this research to research on dynamic assessment in educational settings (Elliott, 2003). It could, for example, be investigated exactly how much instruction children need to improve their analogical reasoning and what this amount of help subsequently means for their readiness to learn by analogy.

Given that the analogical ability is generally assumed to be related to a variety of mathematical competencies besides geometry (e.g., numeric representations, calculation, understanding fractions), our results imply that children's potential growth on tasks with analogical reasoning may contribute to mathematical development besides geometry. This is an important implication for mathematics education. However, in this study we did not assess transfer to other mathematical competencies. We therefore recommend evaluating this issue in future research.

Appendix 2A

Examples of geometric analogy items of various levels of difficulty (Figure 6).

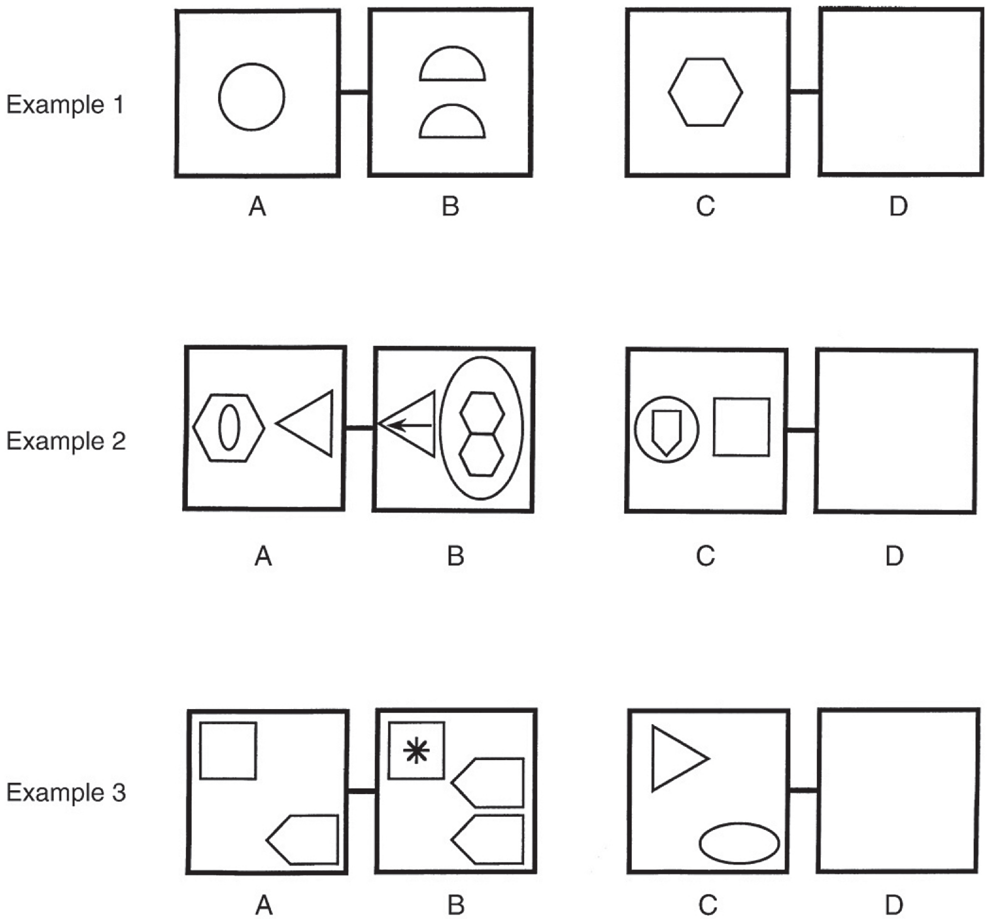

Figure 6.

Appendix 2B

Step by step procedure during the short training.

Step 1. [Encoding]
Question: What did I start with, do you think?
Answer: I first took a few good looks at all the figures in all of these boxes (point to A, B and C).
Step 2. [Inference]
Question: What did I do after that, do you think?
Answer: I then saw that this box (point to A) and this box (point to B) belong together'
Step 3. [Inference]
Question: 'How come that I thought of that, do you think?'
Answer: Experimenter explained for each geometric shape in A separately which transformation was applied to it in B.
Step 4. [Mapping]
Question: Which idea did I come up with next?
Answer: I then thought: "This box (point to A) and this box (point to C) look like each other, because..." (show/explain for all geometrical shapes separately why A looks like C).
Step 5. [Application]
Question: After this, what did I draw in this box (point to D) and why did I do that?
Answer: Well, I thought that I should draw something in this box (point to D) that would make these two boxes (point to C and D) belong to together, just like these two boxes (point to A and B) belong to together.
The experimenter then asked for each geometrical shape in A and B which transformations were applied and explained that the same transformations needed to be applied to the geometrical shapes in C in order to come to the solution drawn in D).

CHAPTER 3

The influence of dynamic testing and working-memory capacity on children's analogical reasoning: A microgenetic investigation using multilevel analysis

Pronk, C.M.E., Elliott, J.G., & Resing, W.C.M. (Submitted). The influence of dynamic testing and working-memory capacity on children's analogical reasoning: A microgenetic investigation using multilevel analysis.
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Abstract
In the current study we investigated the inter- and intra-individual developmental trajectories of analogical reasoning in a dynamic test and non-guided practice setting. The study employed a microgenetic research method together with Multilevel Analysis to investigate developmental trajectories as a function of their background variables and experimental treatment. Background variables included verbal and abstract-visual-spatial working-memory capacity. Participants were 32 children aged 7-8 years with a mean age of 90 months. Half of the children followed a microgenetic design; the others followed a comparable design but were dynamically tested halfway the experiment, all assessment moments involving solving visual-spatial analogies tasks. All test sessions were undertaken individually. After repeated assessment sessions, children showed inter-individual growth in analogical reasoning through non-guided practice, but even more through dynamic testing. Growth through both practice and dynamic testing appeared to be influenced by spatial working-memory capacity. After dividing children into subgroups, multilevel analysis allowed us to display intra-individual developmental trajectories that were similar in amount and rate of analogical reasoning change within each subgroup. These study outcomes suggest a need for more in-depth microgenetic research into dynamic testing of analogical reasoning in combination with working-memory assessment. In particular, comparing the strategy use of subgroups painted by the current study might be very promising in revealing specific strengths and weaknesses that influence particular learning trajectories. This information could be used to better predict and ameliorate children's projected learning trajectories.

3.1 Introduction

The development and training of inductive reasoning, particularly children's capacity to reason by analogy, have been the focus of much research (e.g., Alexander, Willson, White, & Fuqua, 1987; Alexander et al., 1989; Goswami, 1992; Resing, 2000; Tzuriel & George, 2009). In former studies, children older than 6 years have typically displayed clear improvements in analogical reasoning after receiving a brief period of training or, alternatively, after having been given extensive instructions for such tasks as verbal analogies (Resing 1993, 1997), physical problem analogies (Tunteler & Resing, 2007a), concrete pictorial analogies (Hessels-Schlatter, 2002; Schlatter & Büchel, 2000; Stevenson, Resing, & Froma, 2009), and classic geometric analogies (Hosenfeld, Van der Maas, & Van den Boom, 1997a, 1997b; Tunteler, Pronk, & Resing, 2008). In contrast, younger children have tended only to show such gains when they had received extensive training (e.g., Tunteler & Resing, 2007a; Alexander et al., 1989). Therefore, this study focused on grade two children to investigate the development of analogical reasoning as it happens. This form of reasoning was induced by repeated non-guided practice and the use of a dynamic test employing concrete, figural analogies.

Both repeated non-guided practice, and instruction while learning, have been recognized as valuable in investigating developmental trajectories by means of a microgenetic research design (Winne & Nesbit, 2010; Siegler, 2006). According to this design, repeated non-guided practice sessions given during a time of rapidly improving competence permits a high frequency of observations relative to the rate of change. Hence, changes in reasoning become visible at the very moment they happen, enabling the discovery of natural developmental pathways. These developmental pathways may be considered natural, since the practice sessions include no explicit forms of intervention, such as the provision of elaborate instructions or prompting (Flynn & Siegler, 2007; Siegler & Crowley, 1991; Siegler 2006). It is considered that the acquisition and development of cognitive abilities may show differing pathways when acquired through more 'natural' unprompted opportunities than when resulting from instruction. These potentially differing pathways make it useful to examine both in combination (Kuhn, 1995; Bjorklund, Miller, Coyle & Slawinsky, 1997; Opfer & Siegler, 2004; Tunteler et al., 2008). Therefore, in addition to unprompted repeated practice, we included instruction derived from a dynamic test.

Dynamic testing has become increasingly popular for the study of inductive reasoning (e.g., Bethge, Carlson, & Wiedl, 1982; Resing, 2000; Tzuriel, 2000; Tzuriel & Flor-Maduel, 2010; Tzuriel & Kaufman, 1999). Key to this approach is the incorporation of feedback and training during the testing phases (Sternberg & Grigorenko, 2002; Elliott, 2003; Swanson & Lussier, 2001). Conventional, static tests are considered to be means to assess already developed abilities. Dynamic modes of testing are designed to assess developing or yet-to-develop abilities which are the products of underlying, but often unrecognized, cognitive capacities (e.g., Hessels, 2000; Elliott, 2003; Lidz & Macrine, 2001; Resing, 2006; Sternberg et al., 2002; Sternberg & Grigorenko, 2006). Dynamic testing has been found to be a means to gain insight into cognitive and meta-cognitive strategies used by the examinees, their responsiveness to examiner assistance and support, and their ability to transfer learning from the test situation to subsequent unaided situations (Elliott, 2003). In this study, we examined the influence over time of a dynamic approach upon children's inter- and intra-individual developmental trajectories in analogical reasoning.

We also investigated the relationship of working-memory capacity to children's developmental trajectories. An accumulating body of evidence suggests that working-memory capacity is central to reasoning tasks such as the solving of analogies (Tunteler & Resing, 2010; Halford, Wilson & Philips, 2010; Morrison et al., 2004; Primi, 2001) and to learning in school (e.g., Alloway & Alloway, 2010; Alloway, Gathercole, Kirkwood, & Elliott, 2009; Holmes, Gathercole, & Dunning 2009; Swanson, 2008). In many studies the manner and extent to which inductive reasoning is related to working-memory capacity have been explored (e.g., Arendasy & Sommer, 2005; Meo, Roberts, & Marucci, 2007; Richland, Morrison, & Holyoak, 2006; Viskontas, Morrison, Holyoak, Hummel, & Knowlton, 2004; Waltz, Lau, Grewal, & Holyoak, 2000). When solving analogies, children's working-memory appears to be particularly important for encoding and processing the terms of the analogy (Sternberg & Rifkin, 1979).

Working-memory may be considered as the workspace for construction of relational representations for solving a given analogical task while using knowledge stored in semantic memory. This workspace is limited in the number of relations that can be processed in parallel although these typically increase with age and maturation. However, complex relations can be recoded into representations of lower complexity or be segmented into smaller parts in order to process them serially (Halford, et al., 2010; Halford, Wilson & Philips, 1998).

The type of relationship or task that needs to be managed appears to be influenced by a differential involvement of separate components of working-memory. Various components have been investigated in a variety of inductive reasoning or academic tasks (e.g., Raghubar, Barnes & Hecht, 2010; Alloway & Passolunghi, 2011). The age of the child and the differential involvement of these components in different types of tasks were first demonstrated by Alloway, Gathercole & Pickering (2006). In line with Baddeley and Hitch's (1974) working-memory model, they found that children as young as 4 years exhibit a structural organization of memory into a domain general component for processing information and verbal and visual-spatial domain specific components for storage. Furthermore, they found that these components could be assessed in a reliable way. In the present study we explicitly focused on the differential involvement of verbal and visual-spatial working-memory components, to examine their possible role in respect of analogical reasoning development in second graders. We thought it important to examine these components separately with a working-memory assessment that made sufficient storage and processing demands (Alloway, 2007) and which would help us explore their influence on analogical reasoning (Resing, Xenidou-Dervou, Steijn & Elliott, 2012).

Our type of data is traditionally analyzed by means of repeated measures analysis as it involves undertaking the same assessments at intervals over time for a given set of individuals. While repeated measures analysis does not enable the researcher to include in their analyses the variation between individual children's trajectories of performance, multilevel analysis – applied in a specific manner suited for longitudinal data - does enable the researcher to include in their analyses children's individual variation over time (e.g., Van der Leeden, 1998). Typically when employing multilevel analysis data, the individual participants are considered to be the first level units, and one or more grouping variables, for example, school or region, form the units for the higher level(s) within the model. Multilevel analysis of longitudinal datasets, on the other hand, allows one to analyze individual children's growth over time at a macro level, instead of at a micro level. Here the repeated measurements are viewed as the first level units, nested and correlated within individual children, who serve as the second level units (Hox, 2002, 2010; Kreft & De Leeuw, 2007; Snijders & Bosker, 1999; Van der Leeden, 1998). By modeling varying regression coefficients at the session level (Level-1), this form of multilevel analysis yields growth trajectories that typically vary for each individual child

(Level-2). Additionally, this form of multilevel analysis enables the inclusion of two types of explanatory variables in the model: time constant and time varying variables. As a result, it becomes possible to model both the average growth trajectories of each group, as well as the individual growth trajectories of each child (Hox, 2002). Thus analyzing our microgenetic data with this form of multilevel analysis enabled us to inspect growth trajectories (Level-1) for each individual (Level-2) and investigate systematic variation between these trajectories as a function of our background variables – the verbal and spatial working-memory components – and experimental treatment, the dynamic test (Van der Leeden, 1998).

In summary, the main focus of the current study was upon examining inter- and intra-individual developmental trajectories of analogical reasoning in a dynamic test and non-guided practice setting. This differed in several ways from earlier work (e.g., Primi, 2001; Hessels-Schlatter, 2002; Resing, Tunteler, De Jong, & Bosma, 2009; Tzuriel & George, 2009). Our explicit objective was to display by means of a relatively novel approach both children's individual growth trajectories in analogical reasoning performance (a) and systematic variation between these trajectories based on the experimental treatment and background variables – verbal and visual-spatial working-memory capacity (b) (Hox, 2002; Kreft & De Leeuw, 2007; Snijders & Bosker, 1999; Van der Leeden, 1998).

In the current study we, therefore, investigated analogical reasoning performance in second grade children by means of the microgenetic research method and multilevel analysis. In particular, we examined the relationships over time between repeated non-guided practice in analogical reasoning in isolation and repeated non-guided practice combined with a dynamic test session based on the 'graduated-prompts-technique' (e.g., Resing & Elliott, 2011) in children with differing levels of verbal and spatial working-memory capacity.

The objectives of the current study were to examine the inter- and intra-individual developmental patterns and rate of change in analogical reasoning between children, who (a) did or did not receive a dynamic test session, and (b) exhibited larger or smaller verbal and/or spatial working-memory capacity. With respect to (a) it was hypothesized that children who engaged in non-guided practice alone would increase their analogical reasoning performance over time, if they also exhibited greater working-memory performance. However, children who additionally received a dynamic test session were expected to show greater improvement over time, displaying the greatest rate of change after dynamic testing (e.g., Resing, 2000). With respect to (b) it was hypothesized that spatial working-memory capacity would be particularly important for analogical reasoning performance at the first session (e.g., Logie, Gilhooly, & Wynn, 1994; Rasmussen & Bisanz, 2005, Tunteler et al., 2008). In contrast, verbal working-memory capacity would be less influential (Alloway & Gathercole, 2006; Haavisto & Lehto, 2004; St. Claire-Thompson & Gathercole, 2006). Additionally, we expected that spatial working-memory capacity would influence improvement through repeated practice alone. Children in grade two with smaller spatial working-memory capacity were expected to display few changes in analogical reasoning through non-guided practice alone as their workspace for constructing relational representations is more limited (Halford et al., 2010). However, they were expected to exhibit a rather more rapid rate of change in analogical reasoning after dynamic testing (e.g., Carr & Schneider, 1991). The rationale was that dynamic testing was expected to alleviate any working-memory limitations by breaking down the analogical reasoning process into smaller steps that could be processed serially and by providing relational knowledge (Halford et al., 2010; Morrison, Doumas, & Richland, 2011). Children with larger spatial working-memory capacity, on the other hand, were expected to show a more gradual pattern and rate of change over time through repeated practice alone, while receiving additional benefit from the dynamic test (e.g., Tunteler & Resing, 2010).

3.2 Method

Participants

Participants were 32 children aged 7-8 years (18 boys; 14 girls) with a mean age of 90.1 months (*SD* = 4.7 months). They were selected based on their attendance in the second grade of two regular primary middle-class schools located in a midsize town in The Netherlands. Parental informed consent was obtained for each participant.

Design

During the first study weeks, each child's inductive reasoning and working-memory capacity were assessed by means of an Exclusion test and measures of spatial and verbal working-memory. Subsequently, a microgenetic two-pretest-two-posttest control-group design was employed (see Table 1). Children in the treatment condition received a dynamic test session while those in the control (practice) condition received a non-guided practice session. The non-guided practice session featured the same analogy tasks, but, as for the other practice sessions, children received no instruction, help or feedback. Non-guided practice sessions ranged from 20-40 minutes per child and were of equal duration for both conditions. The dynamic test session took 30-60 minutes per child for the treatment condition.

Table 1. Research design

	Session					
Condition	Pretest	1	2	D T[1]	3	4
Practice	x	x	X	-	x	x
DT[1]	x	x	X	x	x	x

Note: [1] DT = Dynamic Test; the practice-condition contained the same items as the DT-condition, but the practice-condition did not involve a dynamic test.

Instruments

Exclusion

Exclusion is a visual inductive reasoning subtest of a Dutch child intelligence test (RAKIT: Revisie Amsterdamse Kinder Intelligentie Test (Bleichrodt, Drenth, Zaal, & Resing, 1984)). The test consists of 40 items each comprising 4 geometric figures. Three of these figures can be grouped together on the basis of a rule that needs to be identified. The task requires the child to select the figure that, in each case, does not fulfill the rule.

Memory span–abstract

Memory Span-abstract is a subtest from the RAKIT that measures children's abstract memory span (RAKIT, Bleichrodt et al., 1984). The test consists of a booklet and small blocks both containing pictures of undefined shapes. The test items in the booklet have sequences of these shapes (2-7) that are shown for only 10 seconds to the child. Then, the child needs to reproduce these sequences with the blocks that have the same shapes printed on them. Although this test supposedly only measures memory span, it could also be considered to measure abstract-visual working-memory capacity. Simultaneous storage and processing are arguably involved in good task performance since the undefined shapes need to be manipulated into something more recognizable to remember, while being held in memory, in order to recall and reproduce longer sequences of these shapes. It is highly likely that our age-group draws on executive resources while performing this task (Alloway & Passolunghi, 2011).

Listening recall and spatial recall

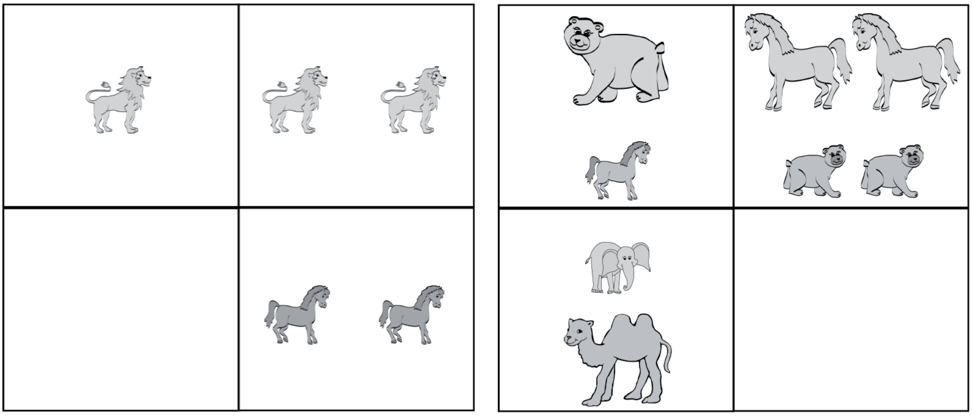
The screening measure from the computerized Automated Working Memory Assessment (AWMA) battery (Alloway, 2007) was used to measure verbal and visual spatial working-memory capacity. The AWMA measures involve both the simultaneous storage and processing of information. The listening recall task utilizes sequences of spoken sentences and the spatial recall task involves recalling the positions of arbitrary shapes that are rotated and/or flipped from left to right.

Figural analogies

The analogical reasoning task consisted of an age-adapted version of the concrete figural analogies measure developed by Stevenson and Resing (e.g., Stevenson, Resing, & Froma, 2009; Stevenson, Touw, & Resing 2011). Four parallel sets were created with 20 open-ended 2x2 figural matrix analogies (see Figure 1). In order to avoid responses based purely on visual recall, the parallel sets were designed to appear different by changing the animal-type and color of the figures of each item over sessions according to fixed rules. The figures consisted of various permutations of six types of animals with three familiar colors, and two sizes, features which would be easily recognized by the children concerned (Goswami, 1992). Items contained up to six transformations including, size, color, number, direction, position, and animal. Children's ongoing engagement was maximized by mixing the order of predicted difficulty of the items. This order of difficulty remained the same over sessions.

At the start of each session, the child was presented with a booklet containing the analogies and baskets with small animal cards for constructing the correct answers in accordance with the transformations used in the items. The examiner explained – while showing the animal cards – the features of the cards: three different colors of the same animal, a set of small and large cards for each animal and that the cards could be flipped. The examiner then turned to the first analogy and said that this was a 'kind of puzzle' with three boxes with animals and a fourth empty box (C-term or D-term), in which the child needed to construct the solution to 'the puzzle' using the animal-cards. After producing each solution, the child was asked how he or she had solved ´the puzzle´. Occasionally some children changed their solutions in response to their verbalizations. In such cases, the final physical arrangement of the cards was scored.

Figure 1. Examples of figural analogies used during non-guided and dynamic testing sessions (adopted from Stevenson et al., 2009)



Note: Left figure: the lion is yellow; the horse is red. Right figure: the small horse, small bears and camel are blue; the large bear, large horses and elephant are yellow.

Figure analogies training

The dynamic test material consisted of an age-adapted set of 7 concrete figural analogies similar to those employed in the other sessions (adapted from Stevenson et al., 2009; 2011). The steps involved are described in Appendix 3A. Unlike most other dynamic test formats, our measure proceeded from difficult to easy items. Where children needed assistance, we sought to provide the minimal amount of help required to solve the tasks independently, in accordance with Resing's (e.g., 1993, 1997) dynamic test format and the 'graduated-prompts-technique'.

The graduated prompts procedure used in the present investigation was originally pioneered by Campione, Brown, Ferrara, Jones & Steinberg (1985) and has been successfully utilized in several of our previous studies (e.g., Resing, 2000; Resing & Elliott, 2011; Resing et al., 2009, 2012; Resing, Steijn, Xenidou-Dervou, Stevenson, & Elliott, 2011). The procedure involves the use, during the dynamic testing session, of a series of adaptive and standardized, hierarchically ordered, metacognitive (self-regulating) and cognitive (task-specific) prompts that proceed from general (2 metacognitive prompts) to increasingly task specific (3 task-specific prompts). The prompts are only provided when and if a child is unable to proceed independently. This delivery of increasingly explicit prompts continues until the child reaches the correct solution. Children are provided with the minimum number of prompts possible to enable progression through the test. While our procedure contrasts with more traditional psychometric approaches whereby progression through the test typically moves from easier to harder items, we have found our approach valuable for enabling even the higher performing children to be trained from the outset, and for assisting all the children to use their newly learned strategies when solving easier items (e.g., Resing, 1993, 2000; Resing & Elliott, 2011; Resing et al., 2009, 2011, 2012).

Scoring

Working-memory capacity test-scores were converted into z-scores and subsequently into standard scores (*M*=100; *SD*=15). The two spatial memory tasks from the RAKIT (memory span-abstract) and the AWMA (spatial recall) were combined into a new variable: MemGrAVS. Verbal working-memory (i.e. the listening recall test) was labeled MemGrV. These two working-memory variables were each split into a 'lower score' and a 'higher score' category, based on the respective median scores on these variables of all 32 children. This yielded two equal groups of 'lower' and 'higher' scoring children for both working-memory variables separately.

The four analogical practice sessions were scored separately for each child. Every session included one booklet of 20 analogical matrices that was the same for all children. Each child received an 'Analogy Score' for each individual session that was the sum total of all analogies that were correctly solved during that session.

Analyses

Multilevel analysis (MLA) was used for analysis of the data. Traditionally, repeated measures analysis has been widely used to analyze data involving repeated measurements of the same individuals. However, microgenetic data sets can also be viewed as comprising multilevel data, where repeated measurements are nested within individuals (Hox, 2002, 2010; Kreft & De Leeuw, 2007; Snijders & Bosker, 1999; Van der Leeden, 1998). MLA appeared to be particularly valuable for the present study as it enabled us to inspect growth trajectories based on data obtained from repeated measurements (Level-1) for each individual (Level-2) and investigate systematic variation between these trajectories as a function of our background variables and experimental treatment (Van der Leeden, 1998). By modeling varying regression coefficients at the session level (Level-1), we obtained growth trajectories that were different for each individual child. Additionally, MLA allowed us to add two types of explanatory variables to the model: time constant and time varying variables. This allowed us to model both the average growth trajectories of each group, as well as the individual growth trajectories of each child (Hox, 2002, 2010).

For reference purposes, Appendix 3B displays the data structure and meaning of the variables used for the MLA. All of the variables contained a meaningful 0-point to facilitate interpretation (Hox, 2002).

3.3 Results

Before examining our research questions in detail, we checked for possible initial differences between children in the dynamic test and practice condition. The mean scores on Exclusion did not differ significantly, nor did the mean number of correct analogical solutions at session one. Means and standard deviations for 'Analogy Score' per session and condition are provided in Table 2.

Table 2. Means and standard deviations of analogy scores per session and condition

	Session				
	1	2	3	4	Total
Condition	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Practice (N = 16)	1.81 (3.17)	2.38 (3.59)	2.75 (4.85)	3.44 (5.32)	2.59 (4.32)
DT (N = 16)	3.00 (2.71)	4.31 (4.85)	8.38 (4.95)	8.06 (4.64)	5.94 (4.39)
Total (N = 32)	2.41 (2.95)	3.34 (4.27)	5.56 (4.90)	5.75 (4.99)	4.72 (4.35)

As described by Hox (2002, 2010), Multilevel Analysis for repeated measurement data was run with nine hypothesized nested models (see Table 3), to examine the inter- and intra-individual developmental patterns and rate of change in analogical reasoning between children, who (a) did or did not receive a dynamic test session in addition to repeated non-guided practice opportunities, and (b) exhibited a larger or smaller verbal and/or spatial working-memory capacity. As stated before, the nested models included the repeated measurements at level 1 and the individual children at level 2 (see Appendix 3B).

Table 3. Results of the likelihood ratio and AIC tests of the multilevel analysis for analogical solutions

	Model tests			
Model Progression[1]	Deviance	*λ(1)*	*P*	AIC
1. Intercept only (Null)	704.1			
2. + Session[2]	670.8*	33.3	< .001	678.8
3. + Spatial Working Memory	665.2*	5.6	.018	675.2
4. + Verbal Working Memory	665.0[4]	.2	.655	677.2
5. + Condition	640.3*	24.7	< .001	652.3
6. + Session Random[3]	624.3*	16.0	< .001	638.3
7. + Session*Condition	621.8[5]	2.5	.113	637.8[6]
8. + Session*Spatial Working Memory[7]	**618.8***	**5.5**	**.019**	**634.8**
9. + Condition*Spatial Working Memory	618.7	.1	.752	636.7

* Significantly better fit than former models at $p \leq .05$; [1]each successive model included one additional variable; [2]the time variable with 4 time points; [3]the slope of the time variable 'session' is modeled to vary across children in this and the following models; [4]non-significant in both the 'fixed effect only' and 'random slopes' model, and therefore no longer included after this point; [5]non-significant and therefore no longer included after this point; [6] the AIC diverts here from the likelihood ratio test [7]this interactions was the last one included in the final model, as the subsequent interaction did not improve the model any further.

Models progressed from those including only fixed effects to those with random slopes. Each successive model included an additional expected variable or interaction, after which it was compared to the previous model with a likelihood-ratio test to determine if the succeeding model had a significantly better fit than the previous one. For reference purposes, Table 3 also provides Akaike's Information Criterion (Akaike, 1987), although this was developed to compare non-nested models. Hox (2010), however, recommends the likelihood ratio test for nested models such as those used in the present study.

Rather than testing the hypotheses one by one in separate analyses, the best fitting model – according to the likelihood ratio test – was used to test our hypotheses by interpreting the interactions and the direct effects of the explanatory variables that made up the interactions together as an integrated system (Hox, 2002, 2010).

In relation to (a) it had been hypothesized that if children exhibited a greater spatial working-memory, repeated non-guided practice alone would improve their analogical reasoning performance over time, but children who had engaged in a dynamic test session would show greater improvement, with the greatest rate of change occurring after dynamic testing in relation to (b) it was hypothesized that spatial working-memory capacity would be particularly important for analogical performance at the first session and over time for gradual improvements in analogical performance through the non-guided practice sessions, but this would not prove to be similarly the case for verbal working-memory capacity.

After running the MLA, the eighth and final model (see Table 3) was proved to be the best fit. The likelihood ratio and the AIC yielded almost the same results. However, as stated above, the former was used to determine the final best fitting model, in accordance with Hox (2010). Regression lines are shown in Figure 2. For reference purposes, the regression equation for the best fitting model is displayed as Appendix 3C.

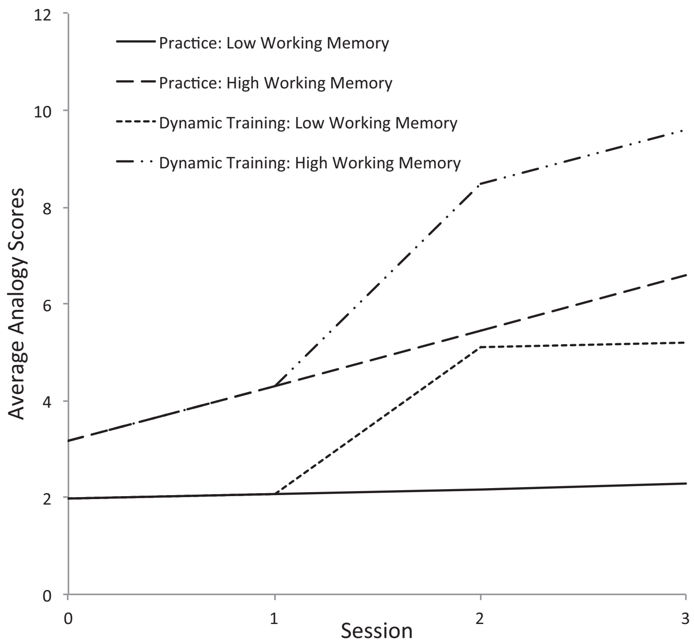


Figure 2. Regression lines per condition and working-memory group

Model 8 included two significant main effects: spatial working-memory and condition, and one interaction: session*spatial working-memory. These effects accounted for four 'subgroups' of children, each displaying a different rate of change over time (see Figure 2). The non-significant 'session' effect and the significant session*spatial working-memory interaction confirmed that children exhibiting a smaller spatial working-memory performance did not improve their analogical performance through repeated practice over time, but children exhibiting a larger spatial working-memory performance did improve their analogical performance through repeated practice over time. This improvement in analogical performance was, as expected, more gradual than the improvement that was induced by the dynamic test, regardless of children's smaller or large spatial working-memory performance. Also, the spatial working-memory main effect confirmed the influence of spatial working-memory on analogical performance at the first session. Verbal working-memory, as hypothesized, did not influence analogical performance. Furthermore, the non-significant interaction of session*condition showed that no significant losses or gains in dynamic-test induced analogical performance occurred at the fourth session for the dynamic test condition. Finally, the non-significant interaction of condition*spatial working-memory showed that no significant differences existed in dynamic test benefits between children exhibiting a smaller or larger spatial working-memory capacity. This confirmed that children with a smaller spatial working-memory capacity would be able to benefit from dynamic testing and improve their analogical performance in the same manner as their peers with a larger spatial working-memory capacity.

To further help interpret these results, we examined a graphical display of the individual children's growth trajectories (Hox, 2002). These trajectories, grouped on the basis of condition and spatial working-memory, are displayed in Figure 3. In general, children within the same condition and the same spatial working-memory group demonstrated similar growth trajectories. Nevertheless, their initial performance at session one displayed a fair amount of individual variability. This factor, in combination with spatial working-memory capacity, appeared to determine the growth trajectories for the sessions thereafter.

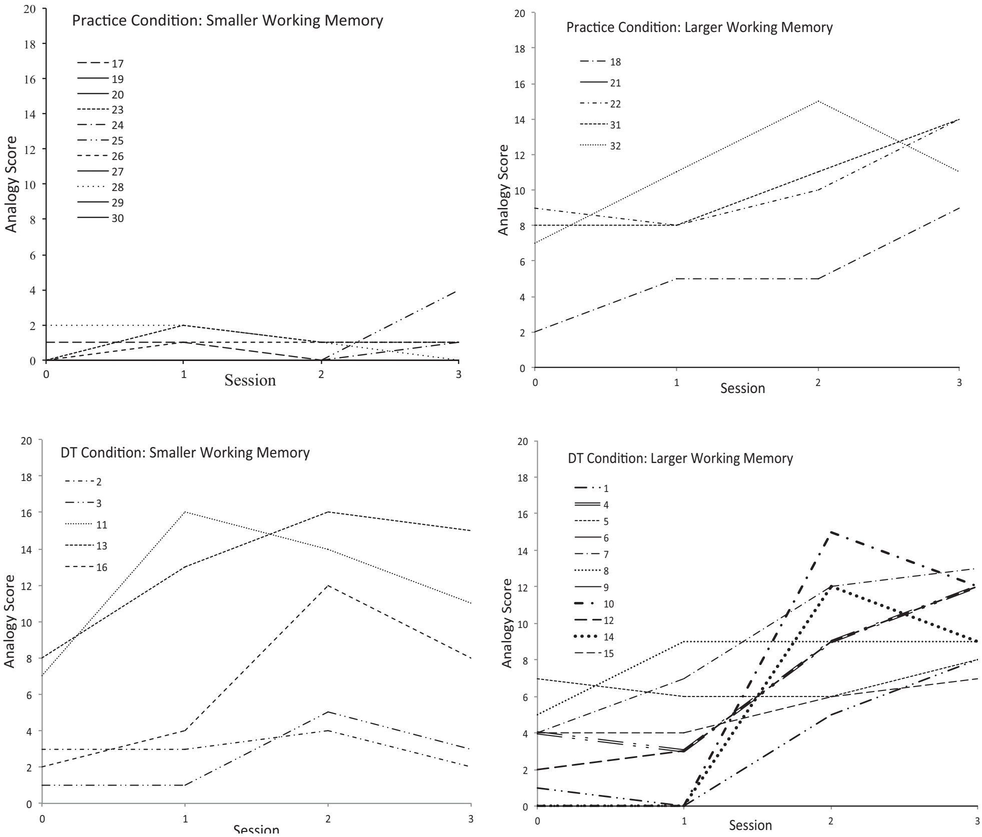
For the practice condition, individual growth trajectories of children exhibiting a smaller spatial working-memory capacity, demonstrated virtually no growth. However, several children exhibiting a larger spatial working-memory capacity displayed individual growth trajectories with a high initial performance and improved analogical scores over time induced by practice alone.

Children in the dynamic test condition with smaller working-memory capacity demonstrated one consistent pattern in common: their analogical reasoning performance deteriorated two sessions after the dynamic testing, although the MLA indicated that this reduction was not significant for the dynamic test condition as a whole. It is interesting to note that two children in this smaller spatial working-memory group obtained a rather puzzlingly high initial score.

Children in the dynamic test condition with larger working-memory capacity displayed the greatest variability in their initial analogical reasoning performance. Children in this group who obtained a low initial score displayed the fastest rate of change of all children across all of the groups; something that might be appropriately described as a 'light bulb effect'. In contrast, other children in this group, as expected, displayed a more gradual rate of change in analogical reasoning without displaying a drop in such performance at any time.

Finally, it is noteworthy that no individual child in any group obtained the maximum score of 20. In fact, only four children obtained a score of 15 or 16. This means that the most difficult items of the analogical task were too difficult for even the highest performing children. These implications of outcome are discussed below.

Figure 3. Individual growth curves for children in the practice condition with smaller working-memory capacity (upper left panel), children in the DT[1] condition with smaller working-memory capacity (lower left panel), children in the practice condition with larger working-memory capacity (upper right panel), and children in the DT condition with larger working-memory capacity (lower right panel).



Note: [1]DT = dynamic test. Caution: some individual growth trajectories are not (completely) visible due to overlap between children; children with solid lines portray complete overlap on the x-axis for all sessions (a 0-score for all sessions).

3.4 Discussion

This study's main aim was to examine the development of analogical reasoning in young children through the use of the microgenetic research method in combination with multilevel analysis. Specifically, these approaches were employed to investigate over time the inter- and intra-individual developmental trajectories and rate of change in analogical reasoning between children assigned to either a dynamic test or non-guided practice condition, while also considering verbal and abstract-visual-spatial working-memory capacity.

As hypothesized on the basis of group averages, children exhibiting larger spatial working-memory who received repeated non-guided practice alone improved their analogical reasoning performance over time, but not as much as those who also received dynamic testing. Furthermore, children who received dynamic testing subsequently displayed the greatest rate of change in performance. This confirms findings reported by Tunteler et al. (2008) and Tunteler and Resing (2010), who, in their microgenetic studies, found similar results with classical geometric analogies when children of grade 1 and 2 were provided with a short training procedure.

Second, as hypothesized, visual-spatial, but not verbal, working-memory capacity was related to a higher level of analogical reasoning performance at the first session. This finding supports earlier research in which differential involvement of working-memory components in various tasks was reported (Alloway & Passolunghi, 2011) and which demonstrated that such elements could be reliably measured in young children (Alloway et al., 2006).

As noted above, spatial working-memory was also related to improvement in analogical performance as a result of repeated practice. Dynamic testing added to this effect, with a subsequently greater average rate of change for all children, irrespective of their spatial working-memory capacity. This is in line with findings from an earlier study by Tunteler and Resing (2010). However, in their study, children with a smaller memory span were able to catch up with their peers after training. In our study there was no differential effect of the dynamic test for children with either small or large working-memory capacity. Therefore, those with greater spatial working-memory capacity continued to display superior analogical performance, even after dynamic testing.

It is unclear why this finding differs from that of Tunteler & Resing (2010). It is possible that the task in the present study was more demanding as it proved to be difficult for all of the participants, irrespective of their level of working-memory. Children in the two studies may have used their working-memory capacity in a different manner when solving the various problems (Halford et. Al, 2010). Interestingly, after inspecting children's individual growth trajectories, the results of the current study appear to have been caused in part by two children with a larger spatial working-memory capacity that increased their analogical reasoning performance very rapidly after dynamic training. This kind of performance change could, under different circumstances, be expected from children with smaller working-memory capacity solving a less complex type of analogical task.

A further explanation for the differing results comes from the observation of the individual growth trajectories of children with smaller spatial working-memory. Those in the dynamic test condition consistently displayed a drop in performance from the session immediately after the dynamic test to the next session. Such children in the practice condition, displayed no growth in analogical performance over time.

In contrast, those in the practice condition with larger spatial working-memory performed in line with our hypothesis that such children would gradually be able to increase their performance through practice alone. Yet, given that only four children were able to score as many as 15 or 16 out of 20, some of the analogies clearly proved too difficult to solve even given the assistance provided. As detailed information about individual children's growth trajectories was not provided in the Tunteler and Resing's (2010) study it is difficult to compare results across the two studies. A key strength of the present study, therefore, was the analysis and graphical display of children's individual growth trajectories over time.

The individual growth trajectories of children's analogical reasoning, against the backdrop of working-memory capacity, once again demonstrated that for the purposes of dynamic testing, the level of task difficulty should not be too high. Children can clearly profit from such a procedure, but only if the task to be solved lies within the individual's particular zone of proximal development (Vygotsky, 1978).

Our findings are also in line with Siegler's (2006) "overlapping waves" theory, which suggests that high initial variability of strategy use often predicts substantial later learning. Interestingly though, certain individual growth trajectories of children with larger spatial working-memory capacity, and who had received dynamic testing, suggested that a certain level of initial performance was not always necessary for rapid learning to occur. Dynamic testing appeared to have had a 'light bulb effect': after dynamic testing these children suddenly displayed a rate of change that exceeded all other learners.

The current study has produced findings that demonstrate that working-memory capacity is an important variable in the performance over time of subgroups that have already been identified as similar in earlier microgenetic studies (e.g., Tunteler et al., 2008; Tunteler & Resing, 2010). While this is consistent with some studies (e.g., Rasmussen & Bisanz, 2005; Morrison, et al., 2011; Alloway et al., 2009), it contradicts Resing et al. (2012), who found significant improvements in analogical reasoning performance irrespective of the working-memory level of the trained children. However, in this earlier study, working-memory was assessed in a simpler manner and a more traditional approach to data analysis was employed.

This distinction leads us to highlight two positive methodological aspects of the present study. Firstly, advanced working-memory tests were used to investigate working-memory components separately (Alloway et al., 2006). These tests might have resulted in improved assignment of children to working-memory groups. Secondly, the current study used a different means of analysis (multilevel analysis for repeated measurement data) that facilitated the inspection of individual growth trajectories in combination, rather than isolation, with systematic variation between these trajectories as a function of the background variables and experimental treatment (Van der Leeden, 1998).

Nevertheless, the current study was unable to display a clear and comprehensive picture of the underlying change mechanisms of the various subgroups. Similar to most studies with a microgenetic research design (Siegler, 2006), these only consisted of a few children per subgroup. This relatively small number of children did not permit us to arrive at comprehensive and strong conclusions. Possibly there was a lack of power to detect certain effects although, as we have shown, some were found in the study. Unfortunately, the small sample size prevented us from adding additional background variables, such as variability in analogical strategy use. Variable strategy use and children's subsequent learning appeared to be clearly present and this fits with findings from many microgenetic studies (Siegler, 2006) and with current theories about the relationship between working-memory capacity and analogical reasoning (e.g., Halford et al., 2010; Alloway et al., 2006).

Further studies with larger samples of children, as well as other age groups and ethnicities (e.g., Resing et al., 2009), larger training programs (e.g., Tzuriel & George, 2009), each employing long-term follow-up are needed to confirm the individual growth trajectories that we found. Additionally, more in-depth microgenetic research examining the combination of dynamic testing of analogical reasoning and working-memory assessment is likely to prove valuable.

Comparison of the variability and strategy use of the four subgroups identified in the current study could help to reveal specific strengths and weaknesses that influence particular learning trajectories. This information could be used to better predict children's learning trajectories and ameliorate potential problems by means of specialized support and instruction.

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 working-memory support or training most suited for an individual child (Morrison et al., 2011) although our 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 interventions for those with learning disabilities. It is contended that information from dynamic testing and assessment of working-memory capacity are likely to be valuable components of a holistic approach to maximizing children's learning. It is hoped that the present study has demonstrated the potential value of a unique approach that can aid the development of this goal.

Appendix 3A

Protocol for an example item of the dynamic test

Step	Instruction	Right Answer	Wrong Answer
0	0.1. Today we are going to make puzzles again. However, this time I will give you some help. 0.2. Just like the other times, there are animals in three boxes [*experimenter points to the boxes*], but there are no animals in the fourth box [*experimenter points to the empty box*]. 0.3. Again you may solve this puzzle by putting the animals in this empty box that you think belong there.	1. Yes, that's correct. 2. How did you solve the puzzle/ why did you put these animals here? [*experimenter continues to request information until the child gives no more information*] **Go to step 6**	1. Your solution isn't completely correct yet. 2. I will put the cards back and give you some help.
1	1.1. First, you think about where to start. 1.2. These boxes belong together [*experimenter points to the upper two terms of the analogy*]. 1.3. These boxes belong together in the same way [*experimenter points to the lower two terms of the analogy*] 1.4. These two boxes also belong together [*experimenter points to the correct two boxes*] 1.5. These two boxes [*experimenter points to the correct two boxes*] belong together in the same way. 6.1. What do you think should be put in the empty box?	1. Yes, that's correct. 2. How did you solve the puzzle?/ why did you put these animals here? [*experimenter continues to request information until the child gives no more information*] **Go to step 6**	1. It's not completely correct yet. 2. I will give some more help. [*experimenter puts the cards back*]
2	Try to solve the puzzle according to these steps: 1. Comparing the boxes 2. Thinking how the boxes belong together 3. Put down your answer with the cards 4. Check if your answer is correct by comparing the boxes.	1. Yes, that's correct. 2. How did you solve the puzzle?/ why did you put these animals here? [*experimenter continues to request information until the child gives no more information*] **Go to step 6**	1. It's (almost/ not completely) correct yet. 2. Let's look at it together [*experimenter puts the cards back*]

Step	Instruction	Right Answer	Wrong Answer
3	3.1. We start by comparing the boxes 3.2. How is this box changed to this box [A:B]? [*changes are requested, until the child provides no more information*] 3.3. And how is this box changed into that box [A:C]? [*changes are requested, until the child provides no more information*] 3.4. Now we shall think some more 3.5. These two [C:D] change like these two [A:B] 3.6. And these two [B:D] change like these two [A:C] 3.7. So.. how do we fill the empty box to solve the puzzle? 3.8. [If needed say: "You can put down the cards."] 3.9. Let's check, is this right? [*point to the row with boxes*] 3.10. Is this also right? [*point to the column with boxes*]	1. Yes, that's correct. 2. How did you solve the puzzle?/ why did you put these animals here? [*experimenter continues to request information until the child provides no more information*] **Go to step 6**	OK, (it's almost correct) I shall give you some more help. [*experimenter puts the cards back*]
4	**This box [A] changed to that box [B] because....** [*experimenter points to the changes and the boxes as he/she mentions them*] 4.1. the animals changed color. The dog is now red and the lion is now blue. 4.2. the animals changed size. The dog is now small and the lion is now large. 4.3. the animals changed in number. Of each animal there are now two. 4.4. the animals changed direction. The dog walked in this direction over here, but it walks in that direction over there. The lion walked in this direction over here and in that direction over there. 4.5. the animals changed places. The dogs are now at the top and the lions at the bottom. **This box [B] changed to that box [D] because....** 4.6. the animal changed into another animal. The lion became an elephant and the dog became a bear. 4.7. the animals changed size. The small lion is now a large elephant. The big dog is now a small bear. 4.8. the animals changed direction. The lion walked this way and the elephant now walks that way. The dog walked this way and the bear now walks that way.	1. Yes, that's correct. 2. How did you solve the puzzle?/ why did you put these animals here? [*experimenter continues to request information until the child gives no more information*]	We are going to solve the puzzle together. [*experimenter puts the cards back*]

Step	Instruction	Right Answer	Wrong Answer
5	**5.1 We start with the animals. Which animals do we need?** [*experimenter points to the changes and the boxes as he/she mentions them*] *If answered incorrectly*: We need the elephants and the bear, because..... here [A:B] the animals remained the same. So here they also remain the same. Here [B:D] the lion changed to an elephant and the dog to a bear. So here you need elephants and bears. **5.2 Which color elephants do we need/ and which color bears?** *If answered incorrectly:* We need blue elephants and red bears, because… here [A:B] the animals changed color. So the elephants become blue and the bears red. Here [B:D] the elephant had the same color as the lion and the bear the same color as the dog. So we need blue elephants and red bears. **5.3 Do we need large or small elephant/ and large or small bears?** *If answered incorrectly*: We need small elephants and large bears, because… here [A:B] the animals changed size. So the elephants need to become small and the bears large. Here [B:D] the animal changed size. The small lion changed into a large elephant and the large dog changed into a small bear. So here the elephants need to be small and the bears large. **5.4 Do we need one or two elephants/ and one or two bears?** *If answered incorrectly*: We need two of each, because... here [A:B] the animals changed from one to two. So here we need two elephants and two bears. Here [B:D] the number of animals remained the same. So here the number also remains the same: two elephants and two bears. **5.5 In which direction do the elephants/ bears need to walk?** *If answered incorrectly*: The elephants walk this way [to the right] and the bears that way [to the left], because… here [A:B] the animals changed direction. So, the elephants now walk this way [to the right] and the bears walk that way [to the left]. Here [B:D] the animals changed direction. The lion walked this direction [to the right] and the elephant that direction [to the left], the dog walked this directions [to the left] and the bear that direction [to the right]. So here the elephants need to walk this direction [to the right] and the bears that direction [to the left]. **5.6 Do we place the elephants at the top or the bottom of the empty box/ and the bears?** *If answered incorrectly*: The elephants we place at the bottom and the bears at the top, because… here [A:B] the animals changed places. So the elephants need to be placed at the bottom and the bears at the top. Here [B:D] the animals remained in the same place. So the lions – that changed into elephants – we put at the bottom and the dogs – that changed into bears – we put at the top. [*The child may have already put the animals down and/or may change/ shift the animals at each sub-step. However, every sub- step needs to be mentioned*]		[In partnership with the child the right answer is created] 1. That is correct! 2. And why is this correct? [*experimenter continues to request information until the child gives no more information*]
6	**Give the correct explanation about the answer**		

Appendix 3B

Structure of analogical reasoning development data

Level-1			
		Range	
Variable Names	Description	Min	Max
Cons	Vector consisting of ones	1	1
Session	Test sessions: four measurement intervals	0	3
SessionEsq	Session squared	0	9
Level-2			
Pupil_ID	Numbers assigned to individual pupils	0	32
Condition	Condition: 0 = practice; 1 = dynamic testing	0	1
MemGrV	Verbal memory group: 0 = low; 1 = high	0	1
MemGrAVS	Spatial memory group: 0 = low; 1 = high	0	1
	Dependent Variable		
Analogy Score	Score for the analogy test per child and session	0	16[1]

Note: [1]*Although the maximum score possible is 20, no child at any session received a score higher than 16.*

Appendix 3C

Regression equations for the final multilevel model

Regression Equation
Solutions Correct = 1.98 + .10 x session + 1.19 x spatial working-memory + 3.02 x condition + 1.04 x session*spatial working-memory.

Note: all variables contain a meaningful 0-point (including session). To obtain regression equations per subgroup, variables must be replaced with group codes and session numbers (practice condition & low working-memory = 00; practice condition & high working-memory = 01; training condition & low working-memory = 10; training condition & high working-memory = 11).

CHAPTER 4

Inter and intra variability in children's strategy change paths when solving figural analogies: A microgenetic dynamic testing study, utilizing multilevel analysis

Pronk, C.M.E., Elliott, J.G., de Rooij, M.J., & Resing, W.C.M. (Submitted). Inter and intra variability in children's strategy change paths when solving figural analogies: A microgenetic dynamic testing study, utilizing multilevel analysis.

Abstract

The current study investigated developmental trajectories in analogical strategy performance of 104 7-8-year-old children. Children received a working-memory assessment and four practice sessions with figural analogies, and were divided into a dynamic training and practice condition. Results showed that training was more influential in analogical strategy improvement than repeated practice. Also, a relationship was found between higher initial variable analogical strategy use and spatial working-memory. This relationship influenced improvement of both behavioral and explained analogical strategies over time, especially for the practice condition. Children with lower initial performances explained mainly copy-strategies, and displayed single strategy use. After training, children displayed and explained more varied analogical and non-analogical strategy use, and included their own rules more often than other non-analogical strategies.

4.1 Introduction

Fine-grained investigation of children's cognitive abilities is complex, as their performance on reasoning and problem solving tasks is often highly variable and can demonstrate significant fluctuation over time (Bjorklund & Rosenblum, 2001; Siegler, 2007). Nevertheless, gaining greater understanding of individual children's learning trajectories in relation to various cognitive processes, such as analogical reasoning (e.g., Tunteler, Pronk, & Resing, 2008), is likely to be valuable for both understanding of the nature of intellectual development and for informing targeted educational intervention at an early stage (e.g., Grigorenko, 2009).

The current study investigates subgroups of children with similar learning trajectories in analogical reasoning, and compares these subgroups' inter- and intra-individual paths of change. For this purpose, judgments are based upon two distinct data sources: a) children's strategies as revealed by their performance behaviors in the test setting and b) their verbal explanations of these strategies.

Analogical reasoning is a basic process that plays an important role in a wide range of higher cognitive processes and represents a core component of intelligence (Halford, 1993; Morrison et al., 2004). Its development in young children has been the focus of much research (e.g., Goswami, 2002) including its role in instruction (Kolodner, 1997), testing (Tzuriel & Kaufman, 1999) and classroom learning (Csapó, 1997; Tzuriel & George, 2009; Vosniadou, 1989). It is argued that, even before primary school entry, many children can utilize analogical reasoning if they are given appropriate assistance and already possess some domain knowledge of the relationships upon which the analogical problems are based (e.g., Goswami & Brown, 1989; Klauer & Phye, 2008; Richland, Morrison & Holyoak, 2006; Singer-Freeman, 2005). Nevertheless, the first few years of primary school are a particular time for the rapid development of analogical reasoning ability (e.g., Siegler & Svetina, 2002; Hosenfeld, Van der Maas, & Van den Boom, 1997b), and it can be assumed that high levels of intra-individual variability will be found in this age group.

Microgenetic Research & Strategy Discovery

The strength of microgenetic research designs is that these provide a high frequency of observations of performance in non-guided practice settings during a time of rapidly improving competence. As a result, changes in reasoning strategies can be observed at the very moment they happen. This enables the discovery of developmental pathways that may be considered to be natural, as the practice sessions include no explicit forms of intervention (Flynn & Siegler, 2007; Siegler & Crowley, 1991; Siegler, 1996).

Findings from microgenetic research studies have resulted in the assertion that development in various domains, from theory of mind (e.g., Flynn et al., 2004) to mathematical skills (Ven, Boom, Kroesbergen, & Leseman, 2012), involves more than the addition of new strategies to a child's current repertoire. Development involves an improved capacity to select the best problem-solving strategy at any given moment, greater reliance on more advanced strategies, and improved execution of those strategies (Siegler, 2006). In their microgenetic study of matrix completion, for example, Siegler and Svetina (2002) found that 6-8-year-old children grew considerably in task performance as a result of repeated practice experiences with figural matrix analogies. Their analogical tasks included up to four transformations (form, size, color and orientation) and utilized a multiple-choice format. The most common error that the children made was choosing an alternative that was a duplicate of one of the terms of the matrix. The frequency of duplicate errors tended to decrease on tasks that were tackled immediately before discovery of the correct solutions, while other errors increased. After discovery of the correct solution strategy, its use became dominant fairly quickly. However, patterns in strategy use may differ when constructed response, rather than multiple-choice, items are used (Stevenson, Resing, & Heiser, manuscript under revision).

Tunteler et al. (2008) conducted a microgenetic study with 6-7-year-old children, using open-ended (constructed response) paper and pencil classical geometric analogies, and very little instruction. Their results indicated that spontaneous improvement in analogical reasoning largely took the form of implicitly correct answers, meaning that children were often unable to explain how they solved the task. Also, spontaneous improvement often consisted of a progression from incomplete to complete analogical answers. These children appeared to possess some rudimentary form of analogical reasoning skill that was accelerated by the opportunity to practice. A short training procedure however, induced improved analogical performance in those children who had failed to demonstrate any analogical reasoning strategies during the preceding unguided practice sessions. After training, the children were largely able to explain their use of correct analogical strategies in solving the tasks. Additional in-depth investigations into intra-individual changes over time revealed several subgroups of children who changed their analogical reasoning performance in a similar fashion (Tunteler et al., 2008). However, it remained unclear in what way children in these subgroups changed, and could explain, their strategies.

In the current study, the inter- and intra-individual paths of change were investigated by means of examination of children's behavioral strategies and their subsequent explanations of these. An increasing body of developmental literature – from arithmetic (Siegler & Stern, 1998) to reading (Farrington-Flint, Coyne, Stiller, & Heath, 2008), to inductive reasoning (Resing, Xenidou-Dervou, Steijn, & Elliott, 2012; Stevenson et al., manuscript under revision) – has pointed to the value of immediate retrospective self-reports of solution strategies together with observations of behavioral solution strategies on the part of children aged five years and older. These self-reports are not expected to impact upon children's developmental trajectories as long as the researcher remains neutral and no feedback is provided (Siegler, 2006). Rather, they may reveal additional information about the depth of understanding a child possesses about the strategies they employ to tackle the problems (e.g., Siegler & Stern, 1998; Church, 1999).

Our microgenetic research design permits examination of two differing measures of strategy use (behavioral and verbal) when children receive either repeated unguided practice or a dynamic-test-type of training. It is possible that the acquisition and developmental pathways of strategies may be different when acquired through more 'natural' unprompted opportunities than through instruction. For this reason, it may be beneficial to examine unprompted practice opportunities and instruction in combination (Kuhn, 1995; Bjorklund, Miller, Coyle & Slawinsky, 1997; Opfer & Siegler, 2004), using both behavioral and self-reported measures of strategy change (Tunteler et al., 2008).

In undertaking assessment geared to inform educational intervention, it has often been considered important to investigate not only what the child is capable of doing without help, but also what he or she can achieve when provided with assistance (e.g., Campione, Brown, Ferrara, Jones & Steinberg, 1985; Grigorenko, 2009). In this study, we therefore examined the influence of a dynamic-test-type of training upon children's inter- and intra-individual developmental trajectories in analogical reasoning. Key to the dynamic test approach is the incorporation of feedback and training during the assessment phase (Sternberg & Grigorenko, 2002; Elliott, 2003; Resing, 2013; Swanson & Lussier, 2001).

Variability in strategy change

Siegler (2007) posits that cognitive variability is an important variable in understanding, predicting, and describing the amount and type of cognitive change. He refers to cognitive variability as the differences between children in terms of change agents, developmental trajectory, generalization, and speed of change, but also changes within the individual child's repertoire of strategies. Tunteler and Resing (2007a) identified three different groups of 5-7-year-old children on the basis of problem analogy task performance over a period of weeks: 1) children showing consistent analogical strategy use; 2) children showing consistent inadequate, non-analogical strategy use; and 3) children showing variable, adequate and inadequate, strategy use. Children in both the trained and untrained conditions manifested variable and diverse strategy use over time. As a way to accurately assess variable strategy use, Siegler (2007) posited the value of trial-by-trial assessments focusing upon four component processes: 1) acquisition of new strategies; 2) increased usage of the most advanced strategies in the child's current repertoire; 3) increasingly efficient execution of strategies; 4) and improved choices among strategies. In the current study, we employed a microgenetic, session-by-session assessment in order to investigate variability in children's use of analogical and non-analogical strategies (Tunteler & Resing, 2007a) and subsequent progress in a) their behavioral responses and b) the verbal explanations that they were able to offer for these.

Working-memory capacity

Working memory capacity is likely to influence children's developmental trajectories, as it is considered to be the workspace for the construction of relational representations for a variety of problem-solving tasks while using knowledge stored in semantic memory (Halford et al., 2010). This workspace is limited in the number of relations that can be processed in parallel (Halford, Wilson & Philips, 1998). Although processing capacity typically increases with age (Siegler, 2006), complex relations can also be recoded into representations of lower complexity, or be segmented into smaller parts, in order to process them serially (Halford, et al., 2010). As a result, more efficient execution of strategy use is likely to reduce working-memory demands (Siegler, 2006). The type of relationship or task that needs to be managed appears to be influenced by the differential involvement of separate components of working-memory even in young children (e.g., Alloway et al., 2006). In line with Baddeley and Hitch's (1974) working-memory model we explicitly focused on the differential involvement of verbal and visual-spatial working-memory components and examined the possible role of each in respect of the development of children's strategy use.

Multilevel Analysis

Studies with microgenetic and cognitive training designs, where data are collected for the same individual at several moments in time, are usually analyzed by means of repeated measures analysis (e.g., Tunteler et al., 2008). However, this does not enable the researcher to include individual children's variations in trajectories of performance. Multilevel analysis, an alternative approach, permits analysis of individual children's growth over time at both a macro and micro level. Multilevel analysis treats the repeated measurements as nested and correlated within individual children (Hox, 2002; Kreft & De Leeuw, 2007; Snijders & Bosker, 1999; Van der Leeden, 1998). By modeling varying regression coefficients at the session level (Level-1), multilevel analysis enables the examination of growth trajectories that may vary for each child (Level-2). Multilevel analysis also permits the inclusion of two types of explanatory variable in the model: a) time constant and b) time varying variables. As a result, it is possible to model the average growth trajectories both of each group and each child (Hox, 2002), as we have suggested in a first, preliminary study using multi-level analysis and a microgenetic design with a relatively small sample (Pronk, Elliott, & Resing, manuscript under revision). In this study, a graphical display of individual growth trajectories within subgroups suggested that initial variability in strategy use was an important variable in predicting growth trajectories (see also, Siegler, 2007). For this reason, the present study included initial variability in strategy use as an additional background variable in a substantially enlarged group of participants.

Research aims and hypotheses

The current study sought: 1) to investigate whether previously identified subgroups of children with similar learning trajectories in analogical reasoning could be detected on the basis of MLA, and 2) to compare the inter- and intra-individual change paths of these subgroups' by examining the children's behavioral strategies and their verbal explanations of these immediately after completing each task item.

We hypothesized that children's analogical reasoning would improve through repeated unguided practice alone, but gains would be even greater following a dynamic-test-type assessment (e.g., Siegler & Svetina, 2002; Tunteler & Resing, 2010; Resing et al., 2012). We expected that this development would be influenced by two additional factors: variability in analogical reasoning as measured at the first session (e.g., Siegler, 2007; Tunteler & Resing, 2007a) and spatial working-memory (e.g., Logie, Gilhooly, & Wynn, 1994; Rasmussen & Bisanz, 2005, Tunteler et al., 2008). Given the nature of the test items, such an outcome was not anticipated in the case of verbal working-memory (Alloway & Gathercole, 2006; Haavisto & Lehto, 2004; St. Claire-Thompson & Gathercole, 2006).

It was anticipated that variability in strategy use at the first session would be positively related to rate and amount of change in the number of behavioral and self-reported transformations, and also to the complete analogical solutions over time, especially for the non-guided practice sessions (Siegler, 2007). However, the progress of children receiving the dynamic-test-type training was expected to be less related to their initial performance as the training was intended to tap into underlying potential rather than current, unassisted performance (e.g., Grigorenko, 2009).

Spatial working-memory was predicted to be positively related to children's number of complete solutions at the first practice session (Halford et al., 1998). However, spatial working-memory was not expected to limit – and therefore be related to – the number of transformations used behaviorally, since this score also included transformations of partial solutions. Complete, but not partial solutions were expected to be limited by the number of relations to be processed in parallel, especially at the first practice session before a child obtained greater skill at the serial processing of transformations (Halford et al., 2010). Spatial working-memory was also expected to influence the number of self-reported transformations at the first session, as the capacity to self-report may be more advanced in children who exhibit a larger activation of advanced reasoning strategies (Siegler & Stern, 1998; Stevenson et al., manuscript under revision).

The path of change of the various subgroups – based on our background variables – was investigated through the component processes of variable strategy use as described by Siegler (2007), utilizing a more explorative and qualitative approach. We expected children to be similar in the amount and rate of change within their subgroup (Siegler, 2006). Children displaying higher working-memory and variable analogical reasoning skills at the start of the study, were expected to have a consistent rate of improvement in their use of analogical strategies. Yet, children with poorer working-memory and only non-analogical skills at the start of this study, were expected to display both losses and gains in practice and subsequently training-induced analogical reasoning (Siegler, 2006). Moreover, the dynamic-test-type of training was designed to increase the capacity to reveal children's 'true' potential, by making the test situation more equitable than traditional testing (Grigorenko, 2009). Therefore we expected a subset of the children – those who displayed little analogical reasoning in the static sessions before training – to be able to improve rather more rapidly than their peers. In contrast, those children who displayed greater evidence of analogical reasoning before training were expected to show a rather more gradual increase in the quality of their reasoning (Tunteler & Resing, 2007a; Tunteler et al., 2008). In accordance with Siegler and Svetina (2002), we anticipated that the children would report a variety of non-analogical strategies (rather than a single strategy) immediately before progressing in the quality of their analogical reasoning. Finally, we expected children to rarely revert back to non-analogical strategies having received training-induced analogical reasoning, but rather in such cases, suboptimal performance would take the form of incomplete answers (Tunteler et al., 2008).

4.2 Method

Participants
Participants[2] (*N*=104) (51 boys; 53 girls) aged 7-8 years (*M*=93.6 months; *SD*=4.8 months) were selected from the second grade of 8 regular primary middle-class schools located in midsized towns in The Netherlands. Informed parental consent was obtained for each participant.

Design
During the first study weeks, each child's inductive reasoning and working-memory capacity were assessed by means of an inductive reasoning test (Exclusion) and measures of spatial and verbal working-memory. Subsequently, a microgenetic two-pretest-two-posttest control-group design with randomized blocks based on the induction test outcomes (described below) was employed (see Table 1). The treatment condition received a dynamic test session while the control (practice) condition received a non-guided practice session. This latter condition contained the same analogy tasks, but, as for the other practice sessions, children received no instruction, help or feedback. Non-guided practice sessions took between 20-40 minutes per child for both conditions. The dynamic test session (for the treatment condition) took 30-60 minutes per child.

2 Enlarged sample of the sample represented in Chapter 3.

Table 1. Research design

	Week					
	1	2 and 3	4 and 5	6 and 7	8 and 9	10 and 11
	Session					
Condition	Pretest	1	2	D T[1]	3	4
Practice	X	x	x	-	x	x
DT	X	x	x	x	x	x

Note: [1] DT-Session: the practice-condition received the same items as the DT-condition. The practice-condition received no dynamic test.

Instruments

Exclusion
Exclusion is a visual inductive reasoning subtest of a Dutch children's intelligence test (RAKIT: Revisie Amsterdamse Kinder Intelligentie Test (Bleichrodt, Drenth, Zaal, & Resing, 1984). The subtest consists of 40 items each comprising 4 geometric figures. Three of the figures can be grouped together on the basis of a rule that needs to be identified. The task requires the child to select the figure that, in each case, does not fulfill the rule.

Listening recall and spatial recall
The screening measure from the computerized Automated Working Memory Assessment (AWMA) battery (Alloway, 2007) was used to measure verbal and visual spatial working-memory capacity. The AWMA measures assess both the simultaneous storage and processing of information. The listening recall task utilizes sequences of spoken sentences, and the spatial recall task involves recalling the positions of arbitrary shapes that are rotated and/or flipped from left to right.

Figural analogies
The analogical reasoning task consisted of an age-adapted version of the concrete figural analogies measure developed by Stevenson and Resing (e.g., Stevenson, Resing, & Froma, 2009; Stevenson, Touw, & Resing, 2011). Four parallel sets were created with 20 open-ended 2x2 figural matrix analogies. In order to avoid responses based purely on visual recall, the parallel sets were designed to appear different by changing the animal-type and color of the figures of each item over sessions according to fixed rules. The figures consisted of various permutations of six types of animals with three familiar colors, and two sizes, features that would be easily recognized by the children concerned (Goswami, 1992). Items contained up to six transformations including size, color, number, direction, position, and animal. Children's ongoing engagement was maximized by arranging for the order of predicted difficulty of the items to be mixed. This pattern of difficulty remained constant over sessions.

At the start of each session, the child was presented with a booklet containing the analogies, and baskets with small animal cards for constructing the correct answers in accordance with the transformations used in the items. The examiner showed the animal cards and explained their features: three different colors for the same animal, a set of small and large cards for each animal, and the option to flip the cards (to point the animal in the opposite direction). The examiner then turned to the first analogy and stated that this was a 'kind of puzzle' with three boxes containing animals and a fourth empty box (C-term or D-term), in which the child needed to construct the solution to 'the puzzle' using the animal cards. After producing each solution, the child was asked how he or she had solved ´the puzzle´. Occasionally some children changed their solutions in response to their verbalizations. In such cases, the final physical arrangement of the cards was scored.

Figure analogies training
The dynamic test material consisted of an age-adapted set of 7 concrete figural analogies similar to those employed in the other sessions (adapted from Stevenson et al., 2009; 2011). Unlike most other dynamic test formats, where problems are typically designed to become increasingly more challenging, our measure proceeded from difficult to easy items. Where children needed assistance, we sought to provide the minimal amount of help required to solve the tasks independently in accordance with Resing's (e.g., 1993, 1997) dynamic test format and the 'graduated-prompts-technique'.

The graduated prompts procedure used in the present investigation was originally pioneered by Campione, Brown, Ferrara, Jones & Steinberg (1985) and has been successfully utilized in a number of other studies (e.g., Resing & Elliott, 2011; Resing et al., 2009; Resing, et al., 2012). The procedure involves the use, during the dynamic testing session, of a series of adaptive and standardized, hierarchically ordered, metacognitive (self-regulating) and cognitive (task-specific) prompts that proceed from general to task-specific. The prompts are only provided when a child is unable to proceed independently. This delivery of increasingly explicit prompts continues until the child produces the complete analogical solution. Children are provided with the minimum number of prompts possible to enable progression through the test. In our earlier investigations, we have found our approach, starting with the more demanding questions, valuable for enabling even the higher performing children to be trained from the outset, and for assisting all the children to use their newly learned strategies when tackling easier items (e.g., Resing, 1993; Resing & Elliott, 2011; Resing et al., 2009, 2012).

Scoring
The four analogical practice sessions were scored separately for each child. Every session included one booklet of 20 analogical matrices that was the same for all participants. Each child obtained several scores per session: 1) a 'Complete Analogies Score' consisting of the total sum of all analogies that were completely and correctly solved; 2) a 'Transformations Correct Score' consisting of the sum of correct transformations (a maximum of 110) as evidenced by the child's behavioral solutions; 3) a 'Transformations Explained Score' consisting of the sum of all correct transformations that were explained as to 'how they solved the puzzle'; 4) if a child did not explicitly mention one or more correct transformations when explaining their solution to an item, their explanation was categorized into one of seven categories (see Appendix 4A). Categories were created on the basis of children's answers and were, in part, based upon the work of other researchers (e.g., Siegler & Svetina, 2002; Tunteler et al., 2008). The number of explanations per category was then totaled per child and session.

The verbal and spatial working-memory variables were each split into 'lower score' and 'higher score' categories, based on the respective median scores on these variables of all

104 children. This yielded two equal groups of ‘lower’ and ‘higher’ scoring children for both working-memory variables separately.

In addition to assigning children to working-memory categories, participants were initially assigned to 3 groups on the basis of variability in analogical reasoning at session one: 1) children showing consistent analogical strategy use (more than 80 percent correct); 2) children showing consistent inadequate, non-analogical strategy use (less than 20 percent correct); and 3) children showing variable, both adequate and inadequate, strategy use (20-80 percent correct) (Siegler & Svetina, 2002; Tunteler & Resing, 2007a; Tunteler et al., 2008). However, because only one participant displayed consistent analogical strategy use at session one, this child was reassigned to the variable analogical reasoning group. Thus, ultimately we ended up comparing only two groups: 1) children showing consistently inadequate, non-analogical strategy use, and 2) children showing both adequate and inadequate (i.e. variable) strategy use.

Taking condition, spatial working-memory capacity, and initial variability as our hypothesized influencing variables, eight subgroups emerged (see Table 2).

Table 2. Subgroups of children derived from the influence of background variables

Group Code[1]	000	001	010	011	111	110	101	100
Condition	0	0	0	0	1	1	1	1
Spatial Working Memory	0	0	1	1	1	1	0	0
Variability	0	1	0	1	1	0	1	0
Number of children[2]	20	7	11	14	17	9	8	18

Note: [1]Group codes based on condition: 0 = practice, 1 = training; spatial working-memory: 0 = lower, 1 = higher; variability: 0 = low,1 = high. [2]Number of children within each subgroup.

Analyses

Multilevel analysis (MLA) was used to analyze the data. Microgenetic data sets can be viewed as comprising multilevel data, where repeated measurements are nested within individuals (Hox, 2002; Kreft & De Leeuw, 2007; Snijders & Bosker, 1999; Van der Leeden, 1998). The use of MLA, in a manner specified for repeated measures data with two levels, enabled us to inspect growth trajectories (Level-1) for each child (Level-2) and to investigate systematic variation between these trajectories as a function of our background variables and experimental treatment (Van der Leeden, 1998). By modeling varying regression coefficients at the session level (Level-1), we obtained growth trajectories that were different for each individual child. We then added two types of explanatory variables to the model: time constant and time varying variables. This enabled us to model both the average growth trajectories of each group and the individual growth trajectories of each child (Hox, 2002, 2010). For reference purposes, Appendix 4B displays the data structure of the variables used for the MLA. All of the variables contained a meaningful 0-point to facilitate interpretation (Hox, 2002).

After running the MLA, we focused on more in-depth analyses of individual growth curves of analogical reasoning over time, and examined the children’s verbal explanations. Siegler (2007) posited the benefit of trial-by-trial assessments of strategy use. In our case, we focused upon the role of the four component processes noted earlier: acquisition of new strategies; increased usage of the most advanced strategies in the child's current repertoire; increasingly efficient execution of strategies; and improved choices among strategies. In order to investigate these, we added a session-by-session assessment per subgroup (see Table 2), over time, of individual children's analogical and non-analogical strategy use. To achieve this, we examined: (a) the number of complete analogical solutions; (b) the number of correct transformations the child produced in both incomplete and complete analogical solutions; (c) the number of these correct transformations the child was able to verbalize; and (d) non-analogical strategy use as indicated by the child's verbal explanations.

4.3 Results

Before examining the findings from our research questions in detail, we checked for possible initial differences between the dynamic test and practice condition. The mean scores on Exclusion did not differ significantly, nor did the mean number of complete analogical solutions, transformations or explanations at session one. Means and standard deviations per session and condition are provided in Table 3.

Table 3. Means and standard deviations of analogy scores per session and condition

	Session			
	1	2	3	4
Condition	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
	Complete Solutions			
Practice (N = 52)	4.10 (4.83)	5.6 (5.56)	5.94 (6.28)	6.31 (6.1)
DT (N = 52)	4.44 (4.33)	6.25 (5.66)	9.38 (5.35)	8.96 (5.61)
Total (N = 104)	4.27 (4.57)	5.92 (5.59)	7.66 (6.06)	7.63 (5.98)
	Correct Transformations			
Practice (N = 52)	51.44 (31.99)	53.88 (35.44)	56.71 (37.09)	58.35 (36.8)
DT (N = 52)	55.88 (28.32)	59.65 (31.97)	78.37 (25.6)	76.08 (26.73)
Total (N = 104)	53.66 (29.63)	56.77 (33.71)	67.54 (33.53)	67.21 (33.28)
	Explained Transformations			
Practice (N = 52)	20.29 (21.11)	23.48 (24.2)	22.54 (24.31)	22.13 (22.69)
DT (N = 52)	23.25 (17.39)	26.98 (21.38)	36.6 (22.25)	32.52 (23.51)
Total (N = 104)	21.77 (19.31)	25.23 (22.79)	29.57 (24.24)	27.33 (23.56)

In accordance with Hox (2002, 2010), the specific Multilevel Analyses for repeated measures data were run with eleven hypothesized nested models for each of our dependent variables: complete analogical solutions, correct transformations, and explained transformations (see Table 4). Repeated measurements were modeled at level 1 and for the individual children at level 2 (see Appendix 4B). Models progressed from those including only fixed effects, to those with random slopes. Each successive model included an additional expected variable or interaction, after which it was compared to the previous model with a likelihood-ratio test to determine if the succeeding model had a significantly better fit than the previous one. For each dependent variable, the final and best fitting model was used to test our hypotheses by interpreting the interactions and the direct effects of the explanatory variables, which made up the interactions, together as an integrated system (Hox, 2002, 2010), rather than by testing the hypotheses one by one in separate analyses. Regression lines were represented in Figures 1-3 for the three final models of the three independent variables. Also, for reference purposes, the regression equations for the final models are displayed in Appendix 4C.

Table 4 Results of the likelihood ratio tests of the multilevel analyses

	Outcome measure								
	1. Solutions Correct			2. Transformations Correct			3. Transformations Explained		
	Likelihood ratio test								
Model Progression[1]	Deviance	*λ(1)*	*P*	Deviance	*λ(1)*	*P*	Deviance	*λ(1)*	*P*
1. Intercept only (Null)	2315.3			3693.3			3379.1		
2. + Session[2]	2207.4*	107.9	< .001	3616.8*	76.5	< .001	3354.0*	25.1	< .001
3. + Variability	2079.5*	127.9	< .001	3520.6*	96.2	< .001	3266.5*	87.5	< .001
4. + Spatial WM	2072.2*	7.3	.006	3518.4[4]	2.2	.14	3264.5[5]	2.0	.16
5. + Verbal WM	2072.0[4]	.2	.65	3518.2[4]	.2	.65	3264.4[4]	.1	.75
6. + Condition	2042.9*	29.3	< .001	3478.2*	42.4	< .001	3237.2*	27.3	< .001
7. + Session Random[3]	1998.9*	44.0	< .001	3419.1*	59.1	< .001	3190.0*	47.2	< .001
8. + Condition*Variability	1993.7*	5.2	0.02	3400.2*	18.9	< .001	3182.0*	8.0	.004
9. + Session*Condition	1987.7*	6.0	0.01	3394.8*	5.4	.02	3176.8*	5.2	.02
10. + Session*Variability[6]	**1973.9***	**13.8**	**< .001**	**3390.1***	**3.7**	**.05**	**3172.3***	**4.5**	**.03**
11. + Session*Variability*Condition	1972.3	1.6	.21	3388.2	1.8	.18	3168.9	3.4	.07

** Significantly better fit than former models at p ≤ .05; [1]each successive model included one additional variable; [2] the time variable with 4 time points; [3]the slope of the time variable 'session' is modeled to vary across children in this and the following models; [4]non-significant in both the 'fixed effect only' and 'random slopes' model, and therefore left out of the model; [5]spatial working-memory was left in the model as this variable was significant in the random slope model (M = 5.55, SD = 2.53 in the final model); [6]this interactions was the last one included in the final model, as the subsequent interaction did not improve the model any further.*

Figure 1. Regression lines for complete analogical solutions for the eight subgroups

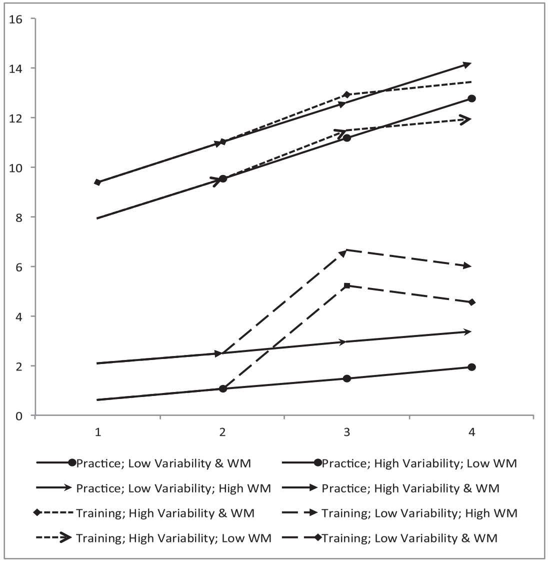


Figure 2. Regression lines for explained transformations for the eight subgroups

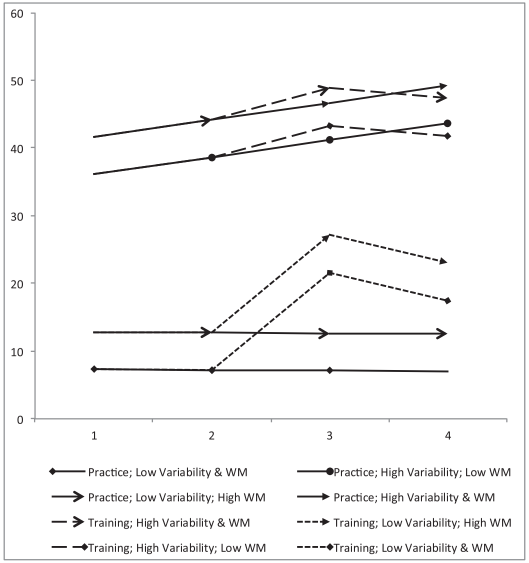
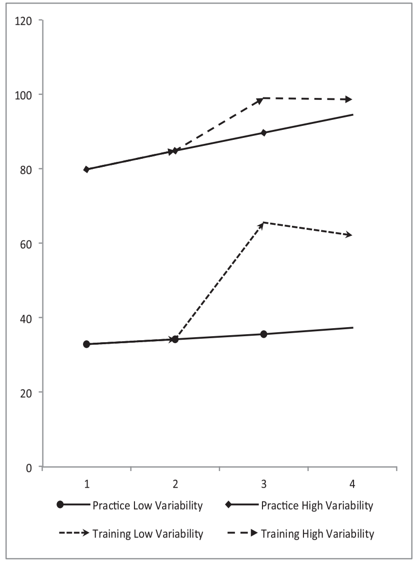


Figure 3. Regression lines for correct transformations for the four subgroups



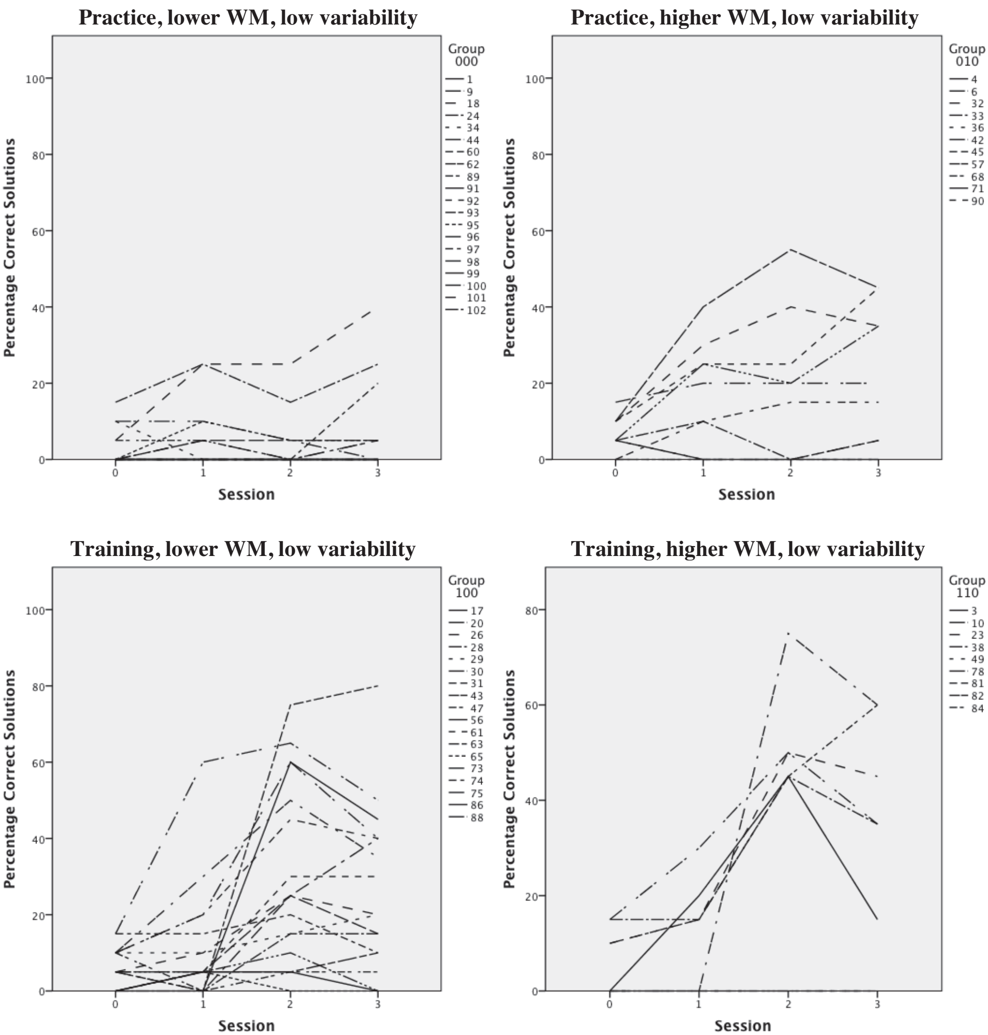
For our first outcome measure – the number of completely correct analogical solutions – model 10 (see Table 4) proved to be the best fit. This model included four main effects: session, variability, spatial working-memory and condition, and three interactions: condition*variability, session*condition and session*variability, thereby accounting for eight subgroups of children (see Figure 1, and Table 2). Outcomes confirmed our hypothesis that repeated practice (positive session effect), but even more than this, the dynamic-test-type of training (positive condition effect), were both related to an improvement in analogical performance over time. As expected, the effect of initial variability in the child's ability to arrive at complete analogical solutions was related to an increase in analogical performance over time (positive session*variability effect). However, this effect, as expected, decreased after the dynamic-test-type training was given (negative condition*variability effect). Unexpectedly, the improved performance of the children who had received the training declined somewhat at session four (negative session*condition effect). This reduction in performance resulted in the high initial variability, trained children showing similar gains to the untrained high initial variable group (non-significant session*condition*variability effect of model 11 in Table 4). As such, model 10 indicated that children with low initial variability in analogical reasoning profited more from the dynamic-test-type training than those children who were already capable of some analogical reasoning at the outset of this study. Finally, as expected, spatial working-memory, but not verbal working-memory (see model 5, Table 4), had a positive influence on the number of complete analogical solutions at session one (spatial working-memory effect).

For our second outcome measure – the number of transformations correct – model 10 (see Table 4) was once again the best fit. The model included three main effects: session, variability, and condition, and three interactions: condition*variability, session*condition and session*variability, which accounted for eight subgroups of children (see Figure 2, and Table 2). This mainly confirmed and paralleled the pattern described above for the outcome measure entitled, 'number of complete analogical solutions'. However, as expected, neither spatial nor verbal working-memory were found to influence the number of transformations correct at session one.

For our third outcome measure – the number of explained transformations – model 10 (see Table 4) once again provided the best fit. This time, the model included three main effects: variability, spatial working-memory, and condition, and three interactions: condition*variability, session*condition and session*variability, and accounted for four subgroups of children (see Figure 3). Although the outcomes were similar as for 'number of completely solved analogical solutions' after having included all main and interaction effects, the main effect of practice (the session effect) was no longer significantly related to the number of explained transformations.

Figures 4-6 display respectively the variation in the three analogical reasoning measures (number of complete analogical solutions, transformations correct, and transformations explained) per subgroup at the individual child level over sessions.

Figure 4 Individual developmental trajectories for percentage *complete analogical solutions* over time per subgroup.



Note: WM = spatial working-memory. Group code numbers: 1st = condition: 0 = practice and 1 = training; 2nd = spatial working-memory: 0 = lower and 1 = higher; 3rd = variability: 0 = low and 1 = high.

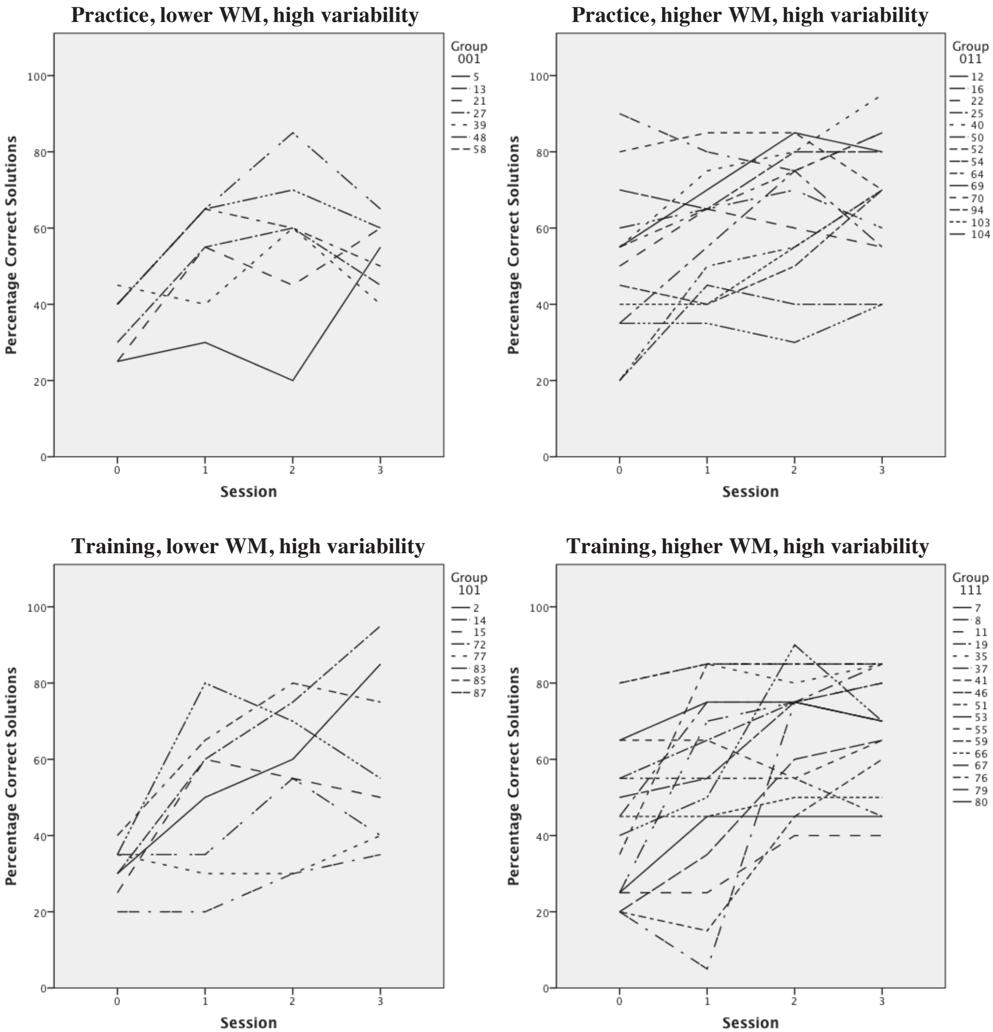
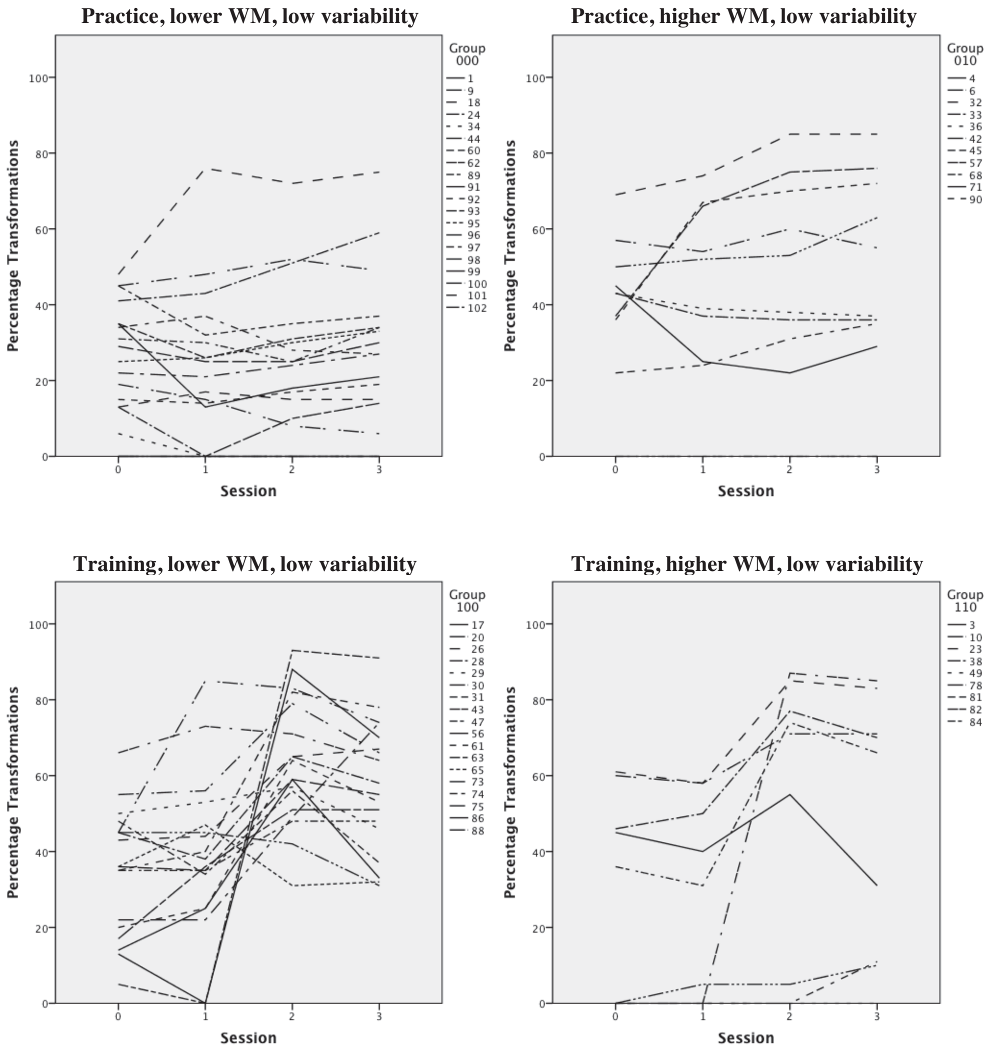

Practice, lower WM, high variability
Group 001
5
13
21
27
39
48
58
Practice, higher WM, high variability
Group 011
12
16
22
25
40
50
52
54
64
69
70
94
103
104
Training, lower WM, high variability
Group 101
2
14
15
72
77
83
85
87
Training, higher WM, high variability
Group 111
7
8
11
19
35
37
41
46
51
53
55
59
66
67
76
79
80
Percentage Correct Solutions
0
20
40
60
80
100
Session
0
1
2
3

Figure 5 Individual developmental trajectories for percentage *correct transformations* over time per subgroup.



Note: WM = spatial working-memory. Group code numbers: 1st = condition: 0 = practice and 1 = training; 2nd = spatial working-memory: 0 = lower and 1 = higher; 3rd = variability: 0 = low and 1 = high.

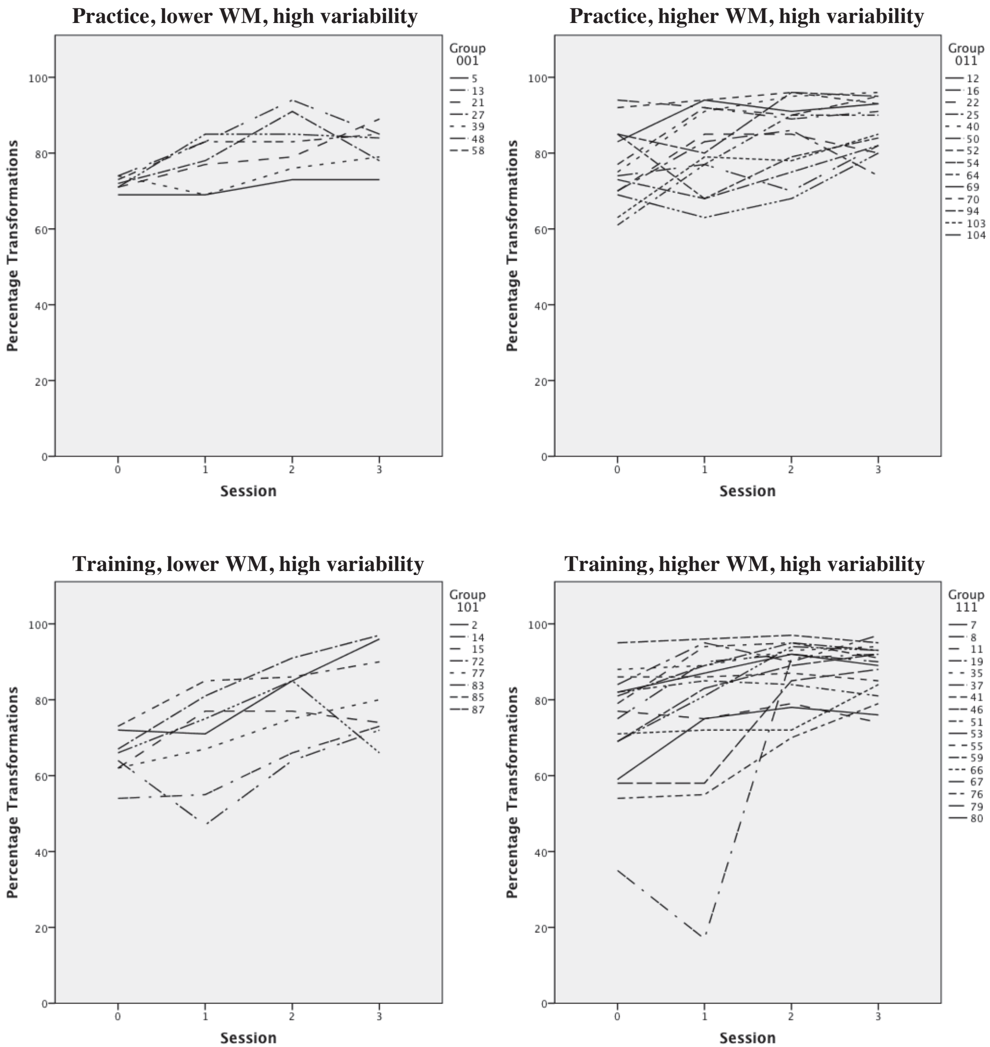
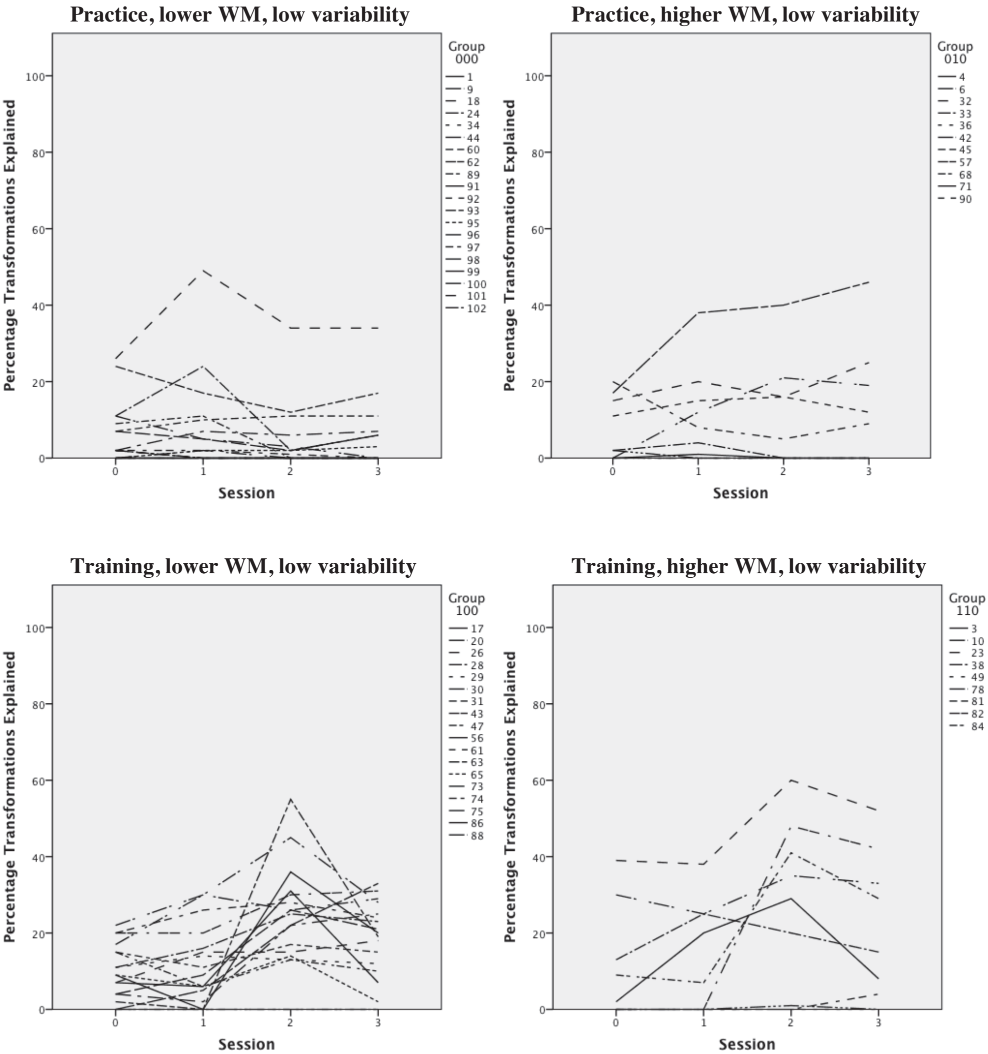
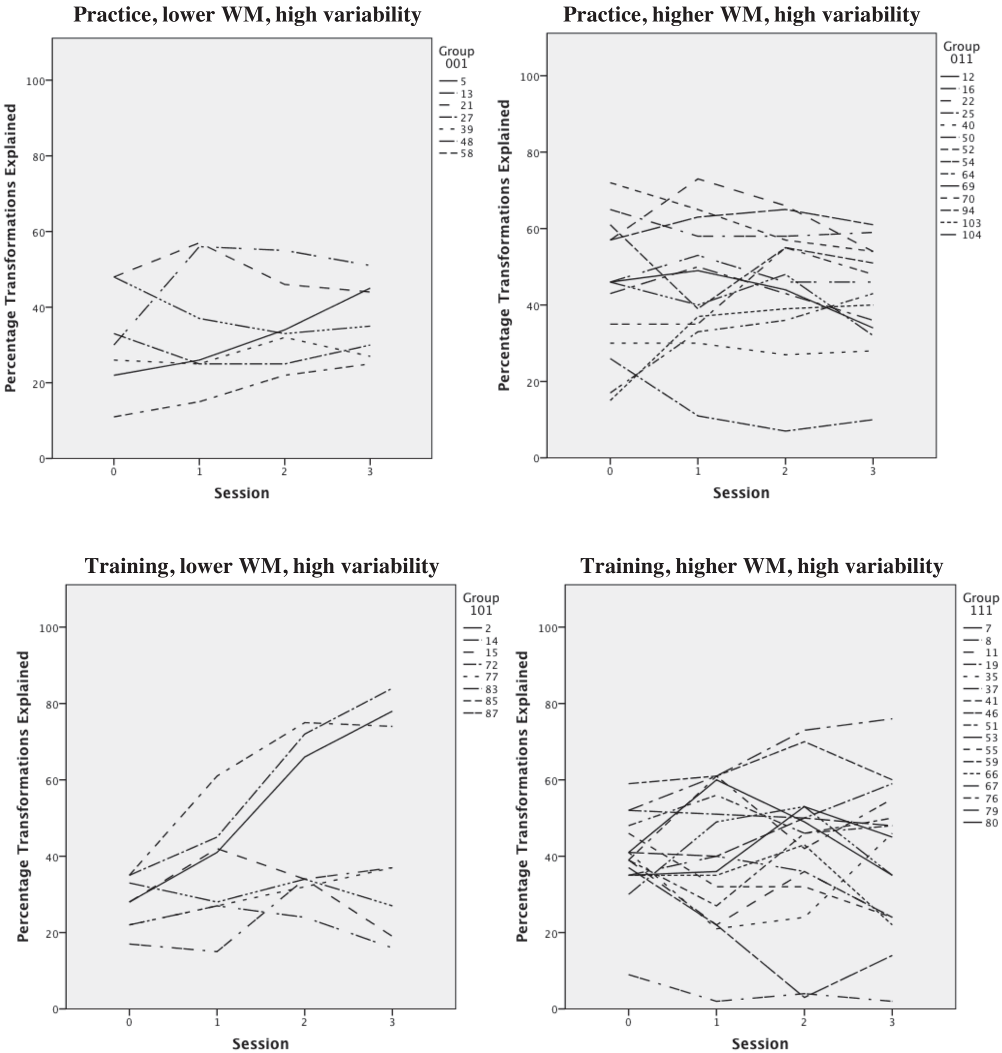

Practice, lower WM, high variability
Percentage Transformations
Session
Group 001
5
13
21
27
39
48
58
Practice, higher WM, high variability
Percentage Transformations
Session
Group 011
12
16
22
25
40
50
52
54
64
69
70
94
103
104
Training, lower WM, high variability
Percentage Transformations
Session
Group 101
2
14
15
72
77
83
85
87
Training, higher WM, high variability
Percentage Transformations
Session
Group 111
7
8
11
19
35
37
41
46
51
53
55
59
66
67
76
79
80

Figure 6 Individual developmental trajectories for percentage *explained transformations correct* over time per subgroup.



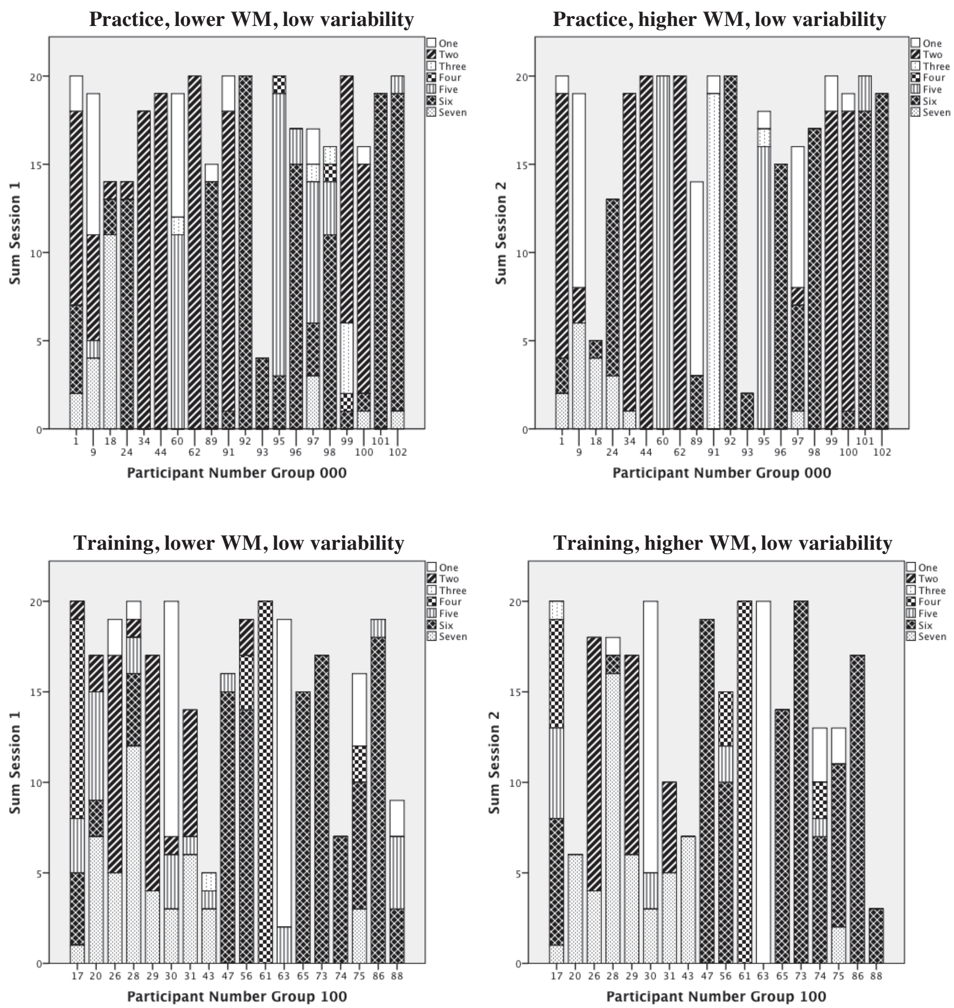
Note: WM = spatial working-memory. Group code numbers: 1st = condition: 0 = practice and 1 = training; 2nd = spatial working-memory: 0 = lower and 1 = higher; 3rd = variability: 0 = low and 1 = high.



Overall, as expected, developmental trajectories for children within the same subgroup were similar. Nevertheless, the amount and rate of change within the subgroups was still highly variable, both between and within children, over sessions. For some children, the dynamic-test-type training appeared to induce relatively rapid improvement in relation to (complete) analogical strategies. However, several of these children demonstrated a dip in performance at the following session. This appeared to be a particular feature of the lower ability group(s), but contrary to our expectations it was not limited to these groups. Developmental trajectories for explained transformations seemed to be the most modest. Those children who showed the most improvement tended to be found in the dynamic-test-type training subgroups and the highest ability subgroup of the practice condition. Nevertheless, the highest ability subgroup of both the practice and training conditions included children displaying significant within and between child variability over time and there appeared to be as many 'losses' as 'gains'. Therefore, at the individual level, the changes in explained transformations were contrary to our hypothesis that trained children with higher working-memory and initial variability would be more consistent in their amount of change and rate of up-take of analogical strategies.

Figures 7-10 display variation and patterns of solutions strategies that were verbalized by individual children within each subgroup per session.

Figure 7 Explanations of solution strategies[1] (non-analogical and implicit analogical) per child and session.



Note: [1]Strategies: 1=copy; 2=part copy; 3=procedural; 4=story; 5=don't know; 6=own rule; 7=implicit analogical. The (partial) absence of a bar represents verbalizations including at least one correct transformation (see Appendix a for a more elaborate description). WM = working-memory. Practice condition: children mainly expressed one or two non-analogical strategies, including mostly copies, part copies and their own rules. Training condition (after training): more varied in their non-analogical strategies per session, included the 'own rule' strategy more often than other strategies and provided more implicit and explicit analogical explanations. Explicit analogical explanations increase especially after training.

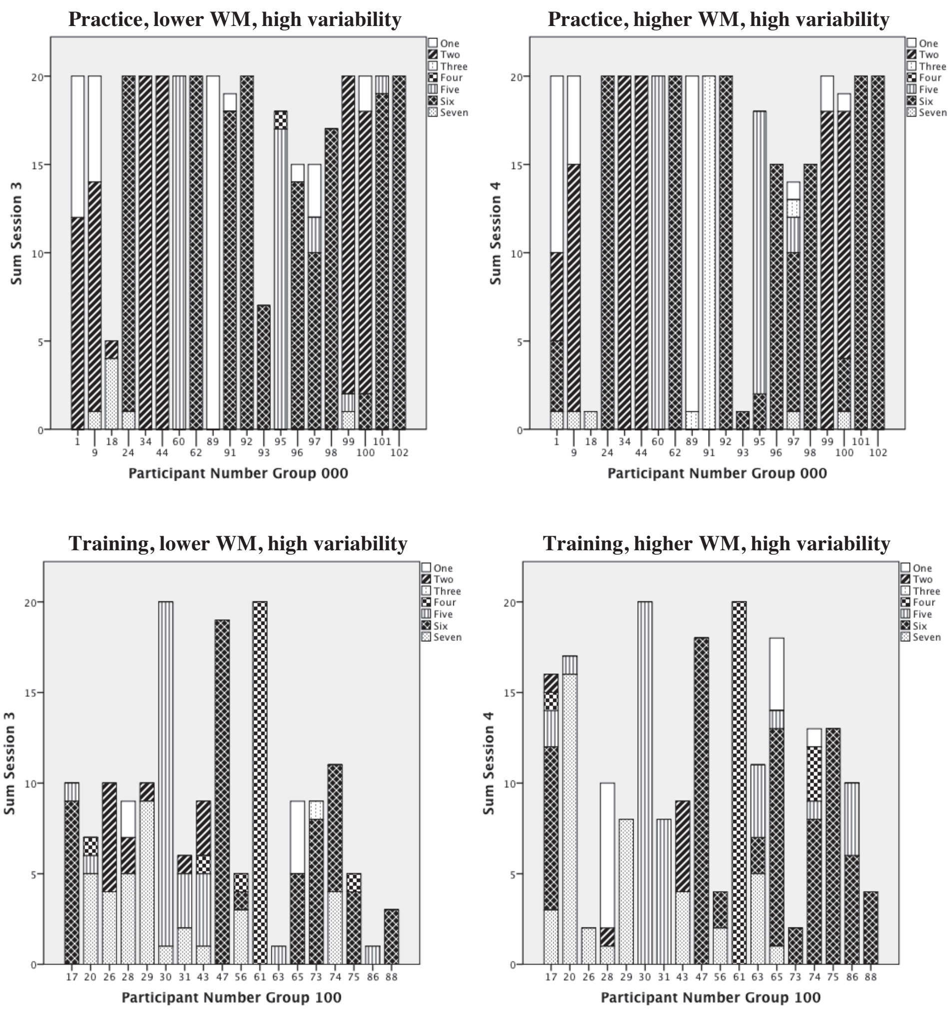
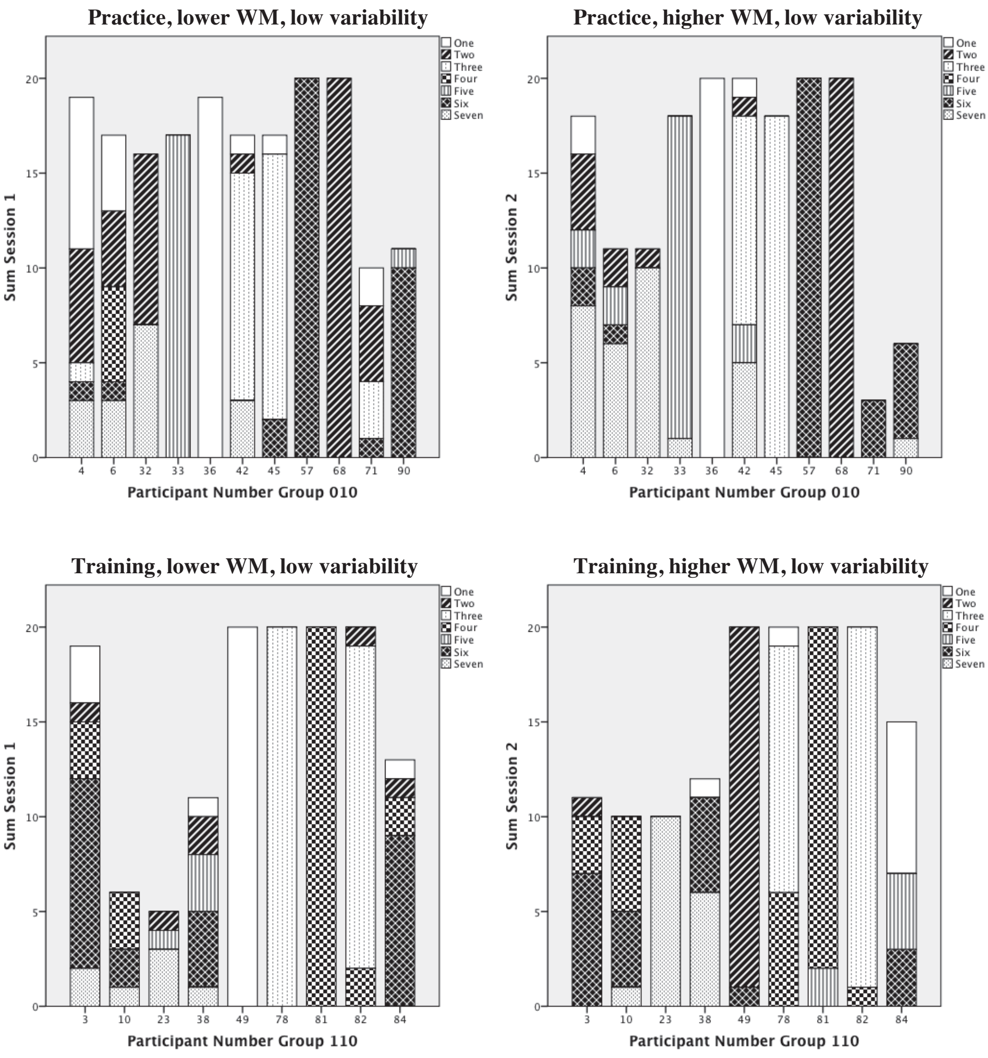
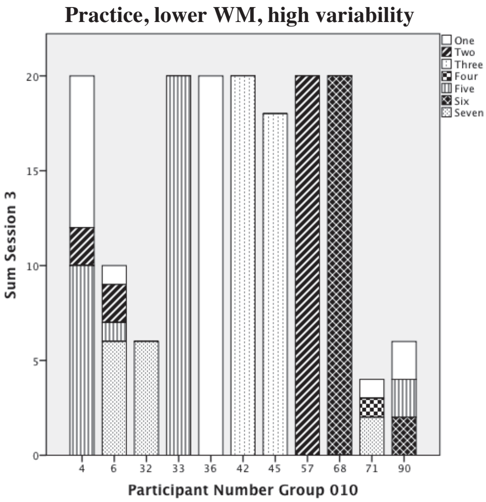
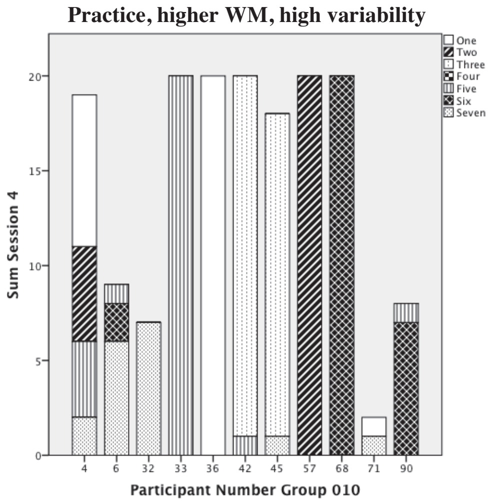

Practice, lower WM, high variability
Sum Session 3
Participant Number Group 000
Practice, higher WM, high variability
Sum Session 4
Participant Number Group 000
Training, lower WM, high variability
Sum Session 3
Participant Number Group 100
Training, higher WM, high variability
Sum Session 4
Participant Number Group 100
One
Two
Three
Four
Five
Six
Seven

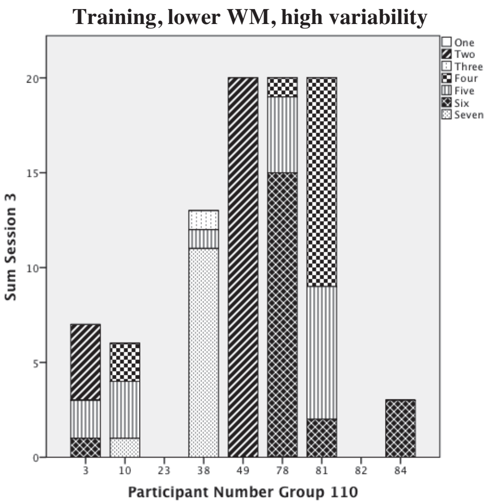
Figure 8 Explanations of solution strategies[1] (non-analogical and implicit analogical) per child and session.



Note: [1]Strategies: 1=copy; 2=part copy; 3=procedural; 4=story; 5=don't know; 6=own rule; 7=implicit analogical. The (partial) absence of a bar represents verbalizations including at least one correct transformation (see Appendix a for a more elaborate description). WM = working-memory. Children that were more variable in number and type of solutions strategies at the start tended to increase in implicit and explicit analogical explanations over time through both practice and training. However, training was able to have a more 'abrupt' effect than practice, as could be seen in child number 82. This child initially gave procedural explanations, but the session after training s/he provided explicit analogical explanations only.


Practice, lower WM, high variability
One
Two
Three
Four
Five
Six
Seven
Sum Session 3
0
5
10
15
20
4 6 32 33 36 42 45 57 68 71 90
Participant Number Group 010


Practice, higher WM, high variability
One
Two
Three
Four
Five
Six
Seven
Sum Session 4
0
5
10
15
20
4 6 32 33 36 42 45 57 68 71 90
Participant Number Group 010


Training, lower WM, high variability
One
Two
Three
Four
Five
Six
Seven
Sum Session 3
0
5
10
15
20
3 10 23 38 49 78 81 82 84
Participant Number Group 110

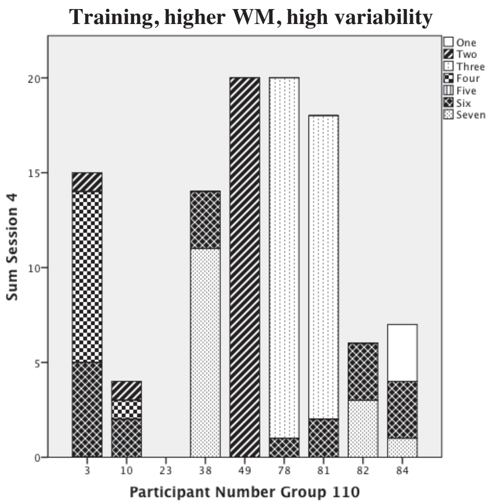
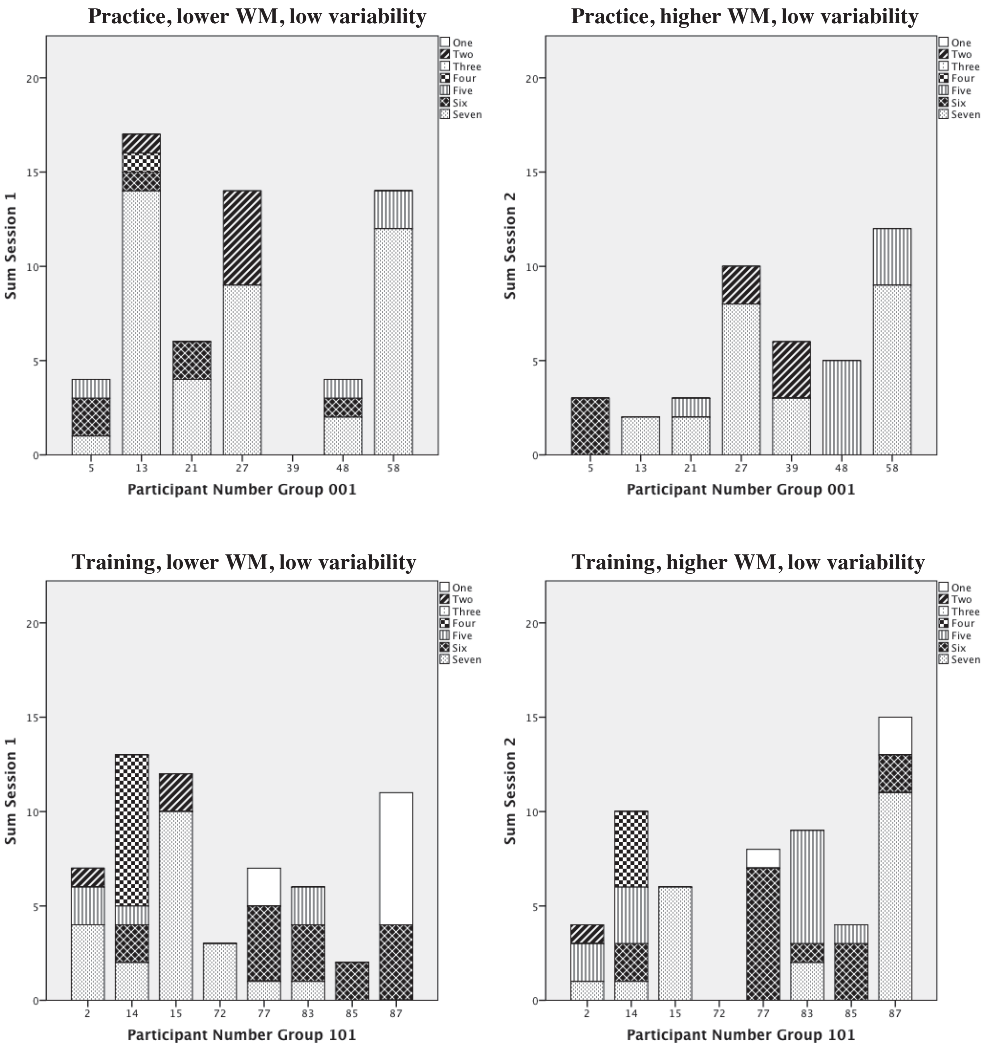

Training, higher WM, high variability
One
Two
Three
Four
Five
Six
Seven
Sum Session 4
0
5
10
15
20
3 10 23 38 49 78 81 82 84
Participant Number Group 110

Figure 9 Explanations of solution strategies1 (non-analogical and implicit analogical) per child and session.



Note: [1]Strategies: 1=copy; 2=part copy; 3=procedural; 4=story; 5=don't know; 6=own rule; 7=implicit analogical. The (partial) absence of a bar represents verbalizations including at least one correct transformation (see Appendix a for a more elaborate description). WM = working-memory. This subgroup appeared very similar in both conditions: children mainly gave explicit and implicit analogical explanations, followed mainly by their own rules and 'don't knows'. No child was unable to explain at least some correct transformation(s) on several items. It also appeared that when these children found the item too difficult they would give an explanation of making their own rule or they explained that they 'didn't know' what they did.

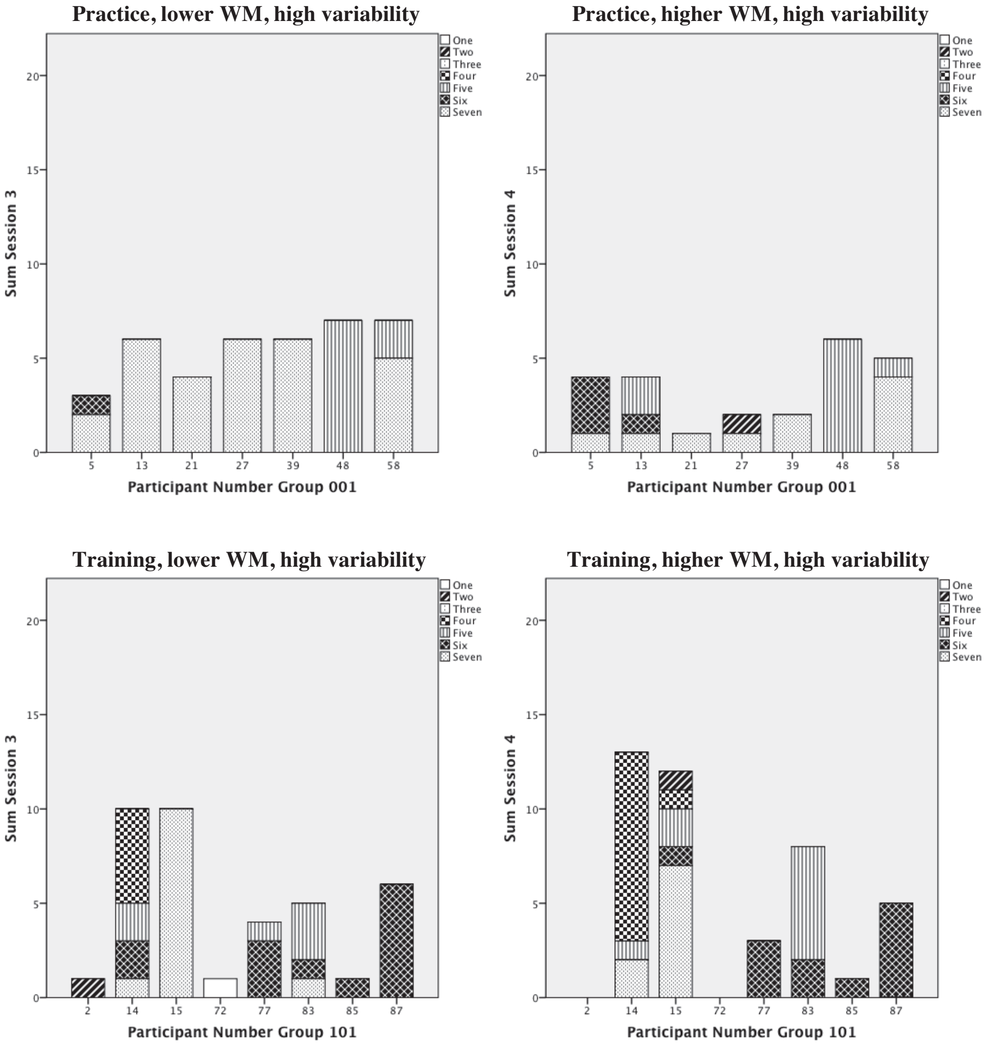
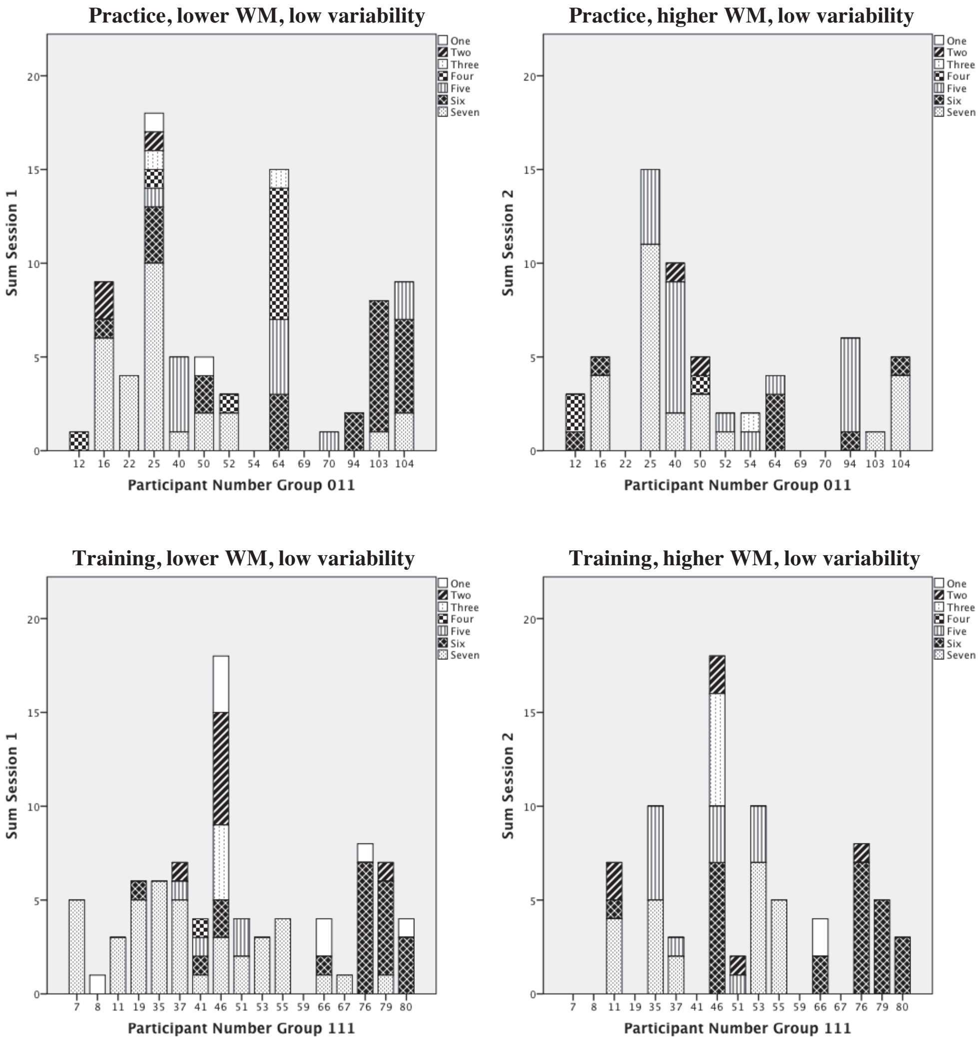
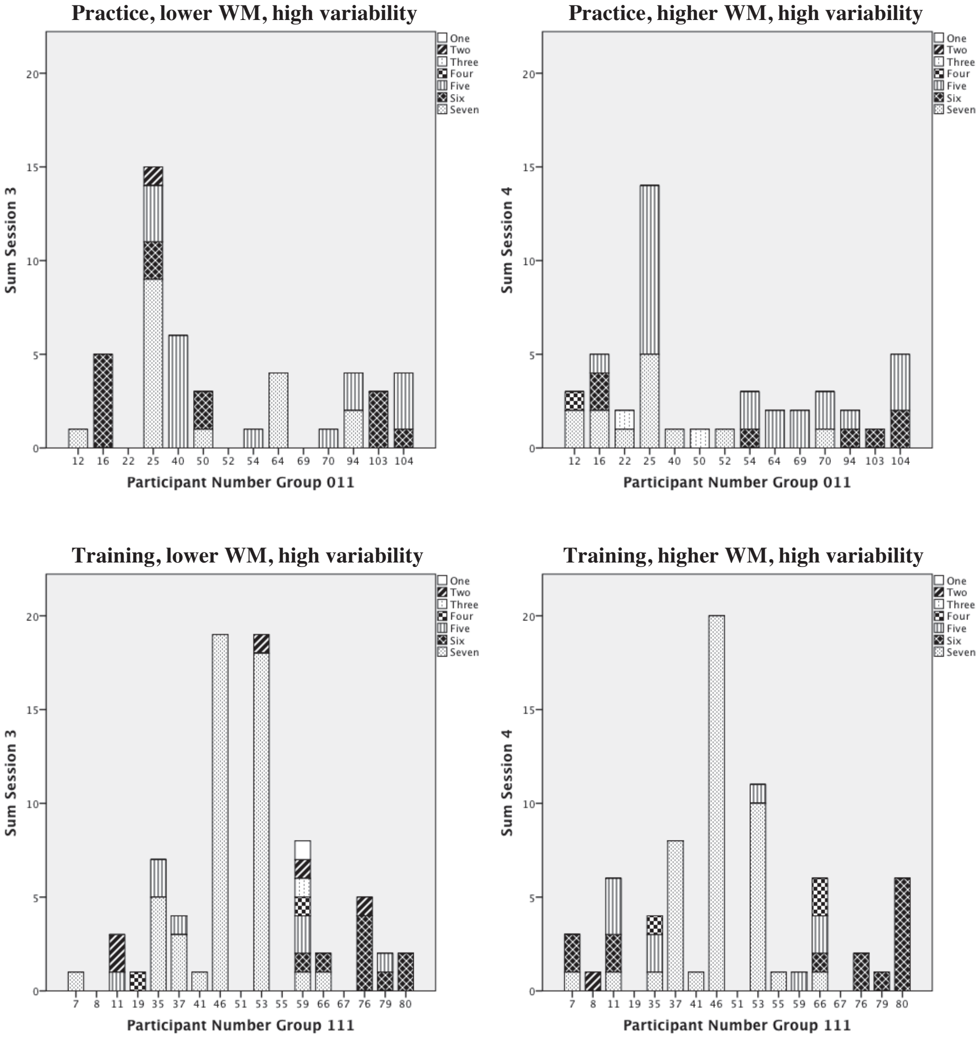

Practice, lower WM, high variability
Sum Session 3
0
5
10
15
20
5
13
21
27
39
48
58
Participant Number Group 001
One
Two
Three
Four
Five
Six
Seven
Practice, higher WM, high variability
Sum Session 4
0
5
10
15
20
5
13
21
27
39
48
58
Participant Number Group 001
One
Two
Three
Four
Five
Six
Seven
Training, lower WM, high variability
Sum Session 3
0
5
10
15
20
2
14
15
72
77
83
85
87
Participant Number Group 101
One
Two
Three
Four
Five
Six
Seven
Training, higher WM, high variability
Sum Session 4
0
5
10
15
20
2
14
15
72
77
83
85
87
Participant Number Group 101
One
Two
Three
Four
Five
Six
Seven

Figure 10 Explanations of solution strategies[1] (non-analogical and implicit analogical) per child and session.



Note: [1]Strategies: 1=copy; 2=part copy; 3=procedural; 4=story; 5=don't know; 6=own rule; 7=implicit analogical. The (partial) absence of a bar represents verbalizations including at least one correct transformation (see Appendix a for a more elaborate description). WM = working-memory.

This subgroup appeared very similar to those in Figure 7 in both conditions. A few children still provided several non-analogical explanations at the start, which were very variable in number and type. At later sessions these explanations were increasingly implicit or explicit analogical.


Practice, lower WM, high variability
Sum Session 3
Participant Number Group 011
12 16 22 25 40 50 52 54 64 69 70 94 103 104
Practice, higher WM, high variability
Sum Session 4
Participant Number Group 011
12 16 22 25 40 50 52 54 64 69 70 94 103 104
Training, lower WM, high variability
Sum Session 3
Participant Number Group 111
7 8 11 19 35 37 41 46 51 53 55 59 66 67 76 79 80
Training, higher WM, high variability
Sum Session 4
Participant Number Group 111
7 8 11 19 35 37 41 46 51 53 55 59 66 67 76 79 80
0 5 10 15 20
One
Two
Three
Four
Five
Six
Seven

As expected, children's strategies within each subgroup were more similar to each other. Copying and using a single strategy was the most common in the lower ability groups for the practice condition. The training condition displayed a greater variation of non-analogical strategies per session, included the 'own rule' strategy more often than other strategies, and resulted in more implicit and explicit analogical explanations. However, those children who, at the start, most varied in the number and type of solution strategies tended to improve their implicit and explicit analogical explanations over time as a result of both training and practice. Nevertheless, as expected, training sometimes had a powerful effect as could be seen in child number 82 in Figure 8 (graph of the training subgroup with a lower working-memory, but high initial variability). This child initially provided procedural explanations, but after training s/he consistently offered explicit analogical explanations. However, and somewhat unexpectedly, many children reverted back to non-analogical, but variable strategies after training.

4.4 Discussion

The current study sought to investigate inter- and intra-individual development in the analogical reasoning of individual children within subgroups of learners. Results will be discussed in accordance with the five dimensions of cognitive change (source, variability, rate, path, and breadth) of the overlapping waves theory (Siegler, 1996; 2006).

The *source of change* refers to underlying factors that encourage changes in reasoning (Siegler, 2006). The current study integrated sources of change and attempted to gain greater understanding of their combined relationship to figural analogical performance measures over time. Both repeated practice over time and dynamic-test-type training were related to complete analogical solutions and correct transformations, although the effect of the dynamic training proved to be greater (e.g., Tunteler et al., 2008; Resing et al., 2012). Unexpectedly, children's explanations about their strategies (explained transformations) were not improved by repeated practice alone. Improved explanations tended to follow training (Tunteler et al., 2008) and initial variability in analogical performance (e.g., Siegler, 2007; Tunteler & Resing, 2007a).

At the initial session, spatial working-memory (Ven et al., 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 explanations. As expected, working-memory was 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 was in accordance with the view that working-memory capacity is likely to place a limit upon complete analogical solutions, where several transformations need to be processed in parallel, until greater skill at the serial processing of transformations is reached (Halford et al., 2010; Richland et al., 2006). The influence of 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 working-memory – at first appear unable to verbalize the correct strategies they used (Siegler & Stern, 1998).

The *variability of change* refers to children's differences in the source, rate, path and breadth of change, as well as changes within individual children's array of strategies (Siegler, 2006, 2007). Our data showed that children's initial variability in the use of analogical strategies was related to development over time, but interestingly, the dynamic-test-type training reduced this influence. This finding reflects the belief 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 training procedure or more frequent training sessions might have decreased the influence of children's initial performance further and could have potentially prevented the reduced performance noted at the final session. 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). The children in our study also displayed variable behavior in several other ways, although these will be discussed in connection to the other dimensions of change.

The *rate of change* refers to the timeline and amount of experience related to development from initial to consistent adequate performance (*rate of uptake)* (Siegler, 2006). In the current study, we made the rate of change and the rate of uptake of the analogical performance measures visible by displaying subgroup regression lines over time, as well as revealing individual children's developmental trajectories within their respective subgroups. It made sense to categorize children into subgroups, as MLA pointed to a significant relationship between the rate of change and our subgroup categorization, as well as individual variation within those subgroups (Van der Leeden, 1998). Inspecting and comparing a combination of analogical performance measures for the various subgroups also proved useful within this context. In accordance with our expectations, individual developmental trajectories generally displayed a fair degree of similarity within subgroups separated by the three analogical performance measures, as well as specific verbalized strategy use (Tunteler et al., 2008; Fabio, 2005). However, 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 already displayed variable analogical reasoning. Nevertheless, 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. Several individual child trajectories showed such a dip at the final session, particularly in the case of those in the lower ability subgroups. The finding that the performance of able children sometimes deteriorated was contrary to our hypothesis that higher ability children who received training, would generally be relatively consistent in their rate of change and uptake of analogical strategies. It is possible that some of the more able children lost interest in explaining all of the various transformations for every task that they solved (Tunteler et al., 2008). In addition, certain transformations may have been more difficult to explain than others (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 extent of children's motivation for tackling the tasks (Siegler & Engle, 1994), or a failure to provide feedback concerning the accuracy of children's answers (Siegler & Svetina, 2002). Also, specific subgroups of children may require a varied and tailored way of instruction (Davidson & Sternberg, 1984) when they are at a particular stage of readiness to learn (Vygotsky, 1978; Alibali & Goldin-Meadow, 1993).

The *path of change* refers to developmental trajectories in terms of sequences of changing knowledge states and problem-solving behavior (Siegler, 2006). We identified seven different verbalized strategies that children employed: providing a full or part copy of another term, giving procedural information, telling a story about the animals, stating that they don't know, offering their own rule, and providing implicit analogical answers (see Appendix 4A). Although quite elaborate, these categories were broadly similar to those identified in other studies of analogical reasoning (e.g., Siegler & Svetina, 2002; Tunteler et al., 2008). Overall, and in accordance with our expectations, 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), where children 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, such a finding was rather less common in Siegler and Svetina's (2002) study than our own. It is possible that our open-ended format, the higher number of potential transformations, and the lack of any instruction and feedback in the practice situations were contributory factors (Stevenson et al., manuscript under revision).

We also anticipated that children would rarely revert back to the use of non-analogical strategies once having demonstrated training-induced analogical reasoning; instead, we expected them to provide incomplete answers in those cases where the correct solution was not found (Tunteler et al., 2008). This hypothesis was confirmed in part as, 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 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 paper, this suggests that children may have (partially) shifted to a more heuristic form of strategy behavior that is quicker to execute, but 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 once again during the final session. This indicated that a 'teachable moment' might have been lost between the final two sessions. It is possible that these children might not have regressed, but rather progressed in their performance *if* they had received another training session between the final two sessions (Vygotsky, 1978; Alibali & Goldin-Meadow, 1993; Siegler, 2006).

In sum, the open-ended figural analogical tasks and dynamic-test-type training proved sensitive for all ability groups, with evidence of variability being demonstrated at several levels. Our examination of several 'sources of change', and use of several analogical and *non-analogical* outcome measures in subgroups of children may prove to be a valuable means of measuring development that could potentially help predict individual development, and identify 'teachable moments' for particular children.

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 could possibly also 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' strategies or 'tell stories' about the animals. 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 quantitatively these more qualitative outcomes and use this information to construct assessment batteries that are able to measure intellectual potential more broadly with the goal that insights from these can be used to better inform educational interventions.

It may also be valuable to investigate children's breadth of change in relation to problem-solving activities of this kind. This construct refers to transfer, to the generalization of newly acquired strategies to other contexts and problems. In a diagnostic context, it may prove useful to add a reversal task to the assessment, where the child is asked to construct a problem (in this case a figural analogy) rather than solve one (Bosma & Resing, 2006; Harpaz-Itay, Kaniel, Ben-Amram, 2006). Findings from these studies suggest that a reversal task may activate higher-level metacognition, additional strategies and better explanations thereof, thus potentially providing additional diagnostic information and direction for (educational) interventions.

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 purpose 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 approach outlined in the present paper represents our attempt to make progress in this direction.

Appendix 4A

Scoring system of the figural analogies

Category	Description	Example
1. Copy	The child indicates that their solution is a copy of another term of the analogy.	'It's this one', while pointing to another term of the analogy.
2. Part copy	The child indicates that s/he has copied part(s) of other term(s), and the behavioral solution confirms this.	'I took that one and that one, but not that one', while pointing to specific animals relating to another term.
3. Procedural	The child gives simple information about picking up particular animal cards and putting them in the empty term.	'I picked up this card and put it down here. I also wanted to lay down this one, but it didn't fit.'
4. Story	The child tells a story about the animals.	'This horse likes that one and this is the mummy and that is her baby.'
5. Don't know	The child indicates ignorance as to how he or she solved the puzzle.	'I don't know', 'I guessed', 'I just liked it.'
6. Own rule	The child indicates that s/he made up a rule and applied it to the analogy. However, this isn't a correct transformation.	'I made this one blue, because there was no blue yet.' Or: 'One bear plus one, so this one needs two.'
7. Implicit analogical	Correct transformations are clearly present in the behavioral solution, but the child only refers to them implicitly.	'I made it just like there,' while pointing to the top two terms and then to the bottom two terms.

Appendix 4B

Structure of analogical reasoning development data

Level-1			
		Range	
Variable names	Description	Min	Max
Cons	Vector consisting of ones	1	1
Session	Test sessions: four measurement moments	0	3
Level-2			
Student	Numbers assigned to individual pupils	0	104
Condition[1]	Condition: 0 = practice; 1 = dynamic testing	0	1
Verbal WM	Verbal memory group: 0 = low; 1 = high	0	1
Spatial WM	Spatial memory group: 0 = low; 1 = high	0	1
Variability	Variable analogical reasoning: 0 = low; 1 = high		
	Dependent Variables		
Complete Analogies	Complete analogical solutions per child and session	0	20
Explanations	Explained transformations per child and session	0	110
Transformations	Correct transformations per child and session	0	110

Note: [1]Since conditions didn't differ for sessions 1 and 2, both conditions were coded 0 for these sessions; after training the dynamic test condition was coded as displayed above

Appendix 4C

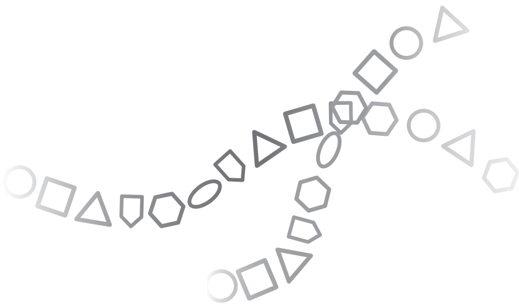
Regression equations per final MLA model of each analogical performance measure

Regression Equation
Solutions Correct = .62 + .44 x session + 7.32 x variability + 1.45 x spatial working-memory + 5.97 x condition – 3.42 x condition*variability – 1.12 x session*condition + 1.56 x session*variability.
Transformations Correct (in behavioral solutions) = 32.96 + 1.41 x session + 46.90 x variability + 34.60 x condition – 20.71 x condition*variability – 4.82 x session* condition + 3.58 x session*variability.
Transformations Explained = 7.30 – .10 x session + 28.79 x variability + 5.55 x spatial working-memory + 22.37 x condition – 12.35 x condition*variability – 3.96 x session*condition + 2.64 x session*variability.

Note: All variables contain a meaningful 0-point (including session). To obtain regression equations per subgroup, replace variables with group codes and session numbers.

CHAPTER 5

What can an analogical construction task reveal about changes in children's problem-solving strategy?



Pronk, C.M.E., Elliott, J.G., de Rooij, M.J., & Resing, W.C.M. (submitted). What can an analogical construction task reveal about changes in children's problem-solving strategy?

Abstract

In this study, improvements in children's analogical performance were assessed, by asking them to construct analogies rather than solve them, as is traditionally the case. Quantitative and qualitative inter- and intra-individual measures were investigated. After holding important background variables (working-memory and initial capacity) constant, results showed that those children, who had made most progress in utilizing and explaining analogical strategies when solving classical analogies, demonstrated similar strengths when asked to construct analogies. It was also shown that the dynamic training resulted in improved capacity on the par of the children to reflect upon the strategies employed. Therefore, adding an analogical construction (transfer) task to dynamic-test-situations could provide additional important information about young children's inter- and intra-individual changes in analogical performance.

5.1 Introduction

The development of inductive (particularly analogical) reasoning in children has been extensively described elsewhere (Goswami, 1992; Morrison et al., 2004), especially its role in cognitive development (Goswami, 2002) and classroom learning (Csapó, 1997; Vosniadou, 1989). The first years of primary school are a time for rapid intellectual development and, unsurprisingly, this results in the variable use of inter- and intra-individual cognitive strategies (e.g., Siegler & Svetina, 2002). In order to gain insight into such processes, analogical tasks, sometimes incorporating dynamic testing procedures (Grigorenko, 2009), have been employed for differentiating and, potentially, predicting children's cognitive development and future educational progress. However, to achieve this, in-depth understanding of children's developmental trajectories is required. Here, the use of a microgenetic research design may prove especially helpful (Siegler & Svetina 2002; Tunteler & Resing, 2007).

Microgenetic research & dynamic testing

Microgenetic research designs involve the detailed study of children at times when they are likely to display rapid developmental growth. To achieve a fine-grained picture, these designs utilize frequent sampling of performance over a relatively short time period. Observation of children's responses, when given repeated practice experiences, enables researchers to identify changes in reasoning strategies and differential developmental trajectories as they happen. Development is considered to occur naturally, as, by design, the practice sessions include no explicit forms of intervention (Flynn & Siegler, 2007; Siegler & Crowley, 1991).

In contrast with traditional forms of assessment, dynamic approaches seek to ascertain what children can achieve when they are provided with tailored assistance during the testing procedure. In line with Vygotskian theory, such a procedure may add important information about children's potential, should they be given an appropriate educational program (Grigorenko, 2009; Resing & Elliott, 2011; Swanson & Lussier, 2001). In fact, a (dynamic) training procedure combined with a microgenetic research design has been found to yield significant differential inter- and intra-individual learning trajectories after both repeated practice, and training experiences (Pronk, Elliott, de Rooij & Resing, submitted; Resing, 2013; Tunteler, Pronk, & Resing, 2008). However, it is unclear whether an analogical construction task, deemed in this case to be an example of transfer of learning, can offer additional and valuable information. It is the exploration of this issue that is reported in the present paper.

Breadth of change (transfer)

According to Siegler's (1996) overlapping waves theory, cognitive change is meaningfully described along five dimensions of change: the source, path, rate, variability and breadth of change. The theory co-evolved alongside the microgenetic research approach as a means to interpret observed developmental processes of variability, choice, and change. The focus of the current study was 'the breadth of change' dimension, which refers to generalization, or transfer, of previous learning to other problems and contexts.

Transfer of learning has been the subject of research for more than a century (Larsen-Freeman, 2013; Engle, 2012). With reference to dimensions such as content and context (Barnett & Ceci, 2002), researchers have differentiated between surface versus deep transfer (Forbus, Gentner, & Law, 1995), formal versus material transfer (Klauer, 1998), and near versus far transfer. Transfer has been found to occur consciously and unconsciously (Day & Goldstone, 2012; Day & Gentner, 2007), instantaneously and very gradually (Siegler, 2006), after task mastery (Siegler, 2006), or after more variable strategic behavior (Perry, Samuelson, Malloy, & Schiffer, 2010).

Transfer of strategies to construction tasks

We attempted to examine differences in children's learning by using an analogical construction (transfer) task after they had earlier received a number of practice opportunities and a dynamic-test-type training procedure geared to help them solve such problems. For this subsequent study, children were not required to solve analogies in the traditional fashion, but instead, were asked to take a more active role by constructing similar problems for the examiner to solve (Bosma & Resing, 2006). To encourage transfer of previously learned strategies, the surface features of the task were the same as those of the classical analogical tasks that had been tackled earlier during the practice and training sessions. We primed the children to draw upon previous learning (Day & Goldstone, 2012) by using the same matrix-format and the same animal cards, which permitted the same types of transformation. Nevertheless, these surface similarities did not necessarily make the process of transfer straightforward. The construction format was more challenging than the open-ended classical version, since the former required children to extract analogical strategies from schemas in their memory in order to construct the transformations. Such complexity was not required when tackling the classical format (Martinez, 1999). Effective constructors in our sample were therefore assumed to have gained a more thorough or 'deeper' understanding of the underlying principles of the analogical tasks (Harpaz-Itay et al., 2006; Perkins, 1992). It would appear that patterns in strategy use might differ when constructed response tasks (Stevenson, 2012), or construction tasks (Harpaz-Itay et al., 2006) are employed rather than multiple-choice tasks (Stanger-Hall, 2012).

Some patterns in strategy use in young children's performance on figural analogies have already emerged. Siegler & Svetina (2002), for example, found that when children were given analogical tasks with a multiple-choice format, the most common error was the selection of a duplicate of one of the matrix cells.

Providing children with the opportunity to move beyond practice experiences to engagement in problem construction may shed light on individual differences in their developing use of strategic reasoning (Pittman, 1999; Kim, Bae, Nho, & Lee, 2011; Haglund & Jeppsson, 2012; Siegler, 2006). As such, the analogical construction task used in the current study served a twofold purpose. First, we sought to assess the extent to which children's learning in relation to performance on a traditional analogical task subsequently transferred to one that involved construction. Second, we examined the ways in which this may provide additional information, both qualitative and quantitative, that could be used within a dynamic assessment context (Grigorenko, 2009; Resing, 2013).

To aid our analysis, we made use of immediate retrospective self-reports (Siegler & Stern, 1998; Church, 1999; Bosma & Resing, 2006). For children aged five years and older, an increasing body of literature points to the strength of combining observations of behavioral solution strategies with immediate retrospective self-reports. The value of this approach has been found in studies of arithmetic (Siegler & Stern, 1998), reading (Farrington-Flint, Coyne, Stiller, & Heath, 2008), and inductive reasoning (Resing, Xenidou-Dervou, Steijn, & Elliott, 2012; Stevenson, Hickendorff, Resing, Heiser, & de Boeck, 2013).

Initial ability and working memory

Two additional factors were included in this study: initial ability in task performance and working memory. These have been regarded as important indicators of future task performance that draws upon previously learned material (Day & Goldstone, 2012; Rittle-Johnson, Star, & Durkin, 2009). Working memory, which typically becomes more efficient with age (Siegler, 2006), is considered to be the workspace for the construction of relational representations (Halford, Wilson, & Philips, 2010). If processed in parallel, only a limited number of relations can be constructed at any one time (Halford, Wilson & Philips, 1998). However, complex relations can be recoded into representations of lower complexity, or be segmented into smaller parts, in order that these can be processed serially (Halford et al., 2010). More efficient execution of strategy use is therefore likely to reduce working-memory demands (Siegler, 2006).

Research aims and hypotheses

In this study, a transfer task requiring the construction of analogies was employed in order to examine children's progress in analogical performance. To achieve this, we utilized quantitative and qualitative, inter- and intra-individual measures.

1. A first set of hypotheses concerned the number of correct analogies that a child would be able to construct. We expected that this would be related to (1a) spatial working-memory (Halford et al., 2010; Rasmussen & Bisanz, 2005), and (1b) initial performance on traditional analogical tasks (Day & Goldstone, 2012). When holding these background variables constant, we did not expect to find a relationship between children's progress in the number of analogical tasks they correctly solved following (1c) repeated practice experiences or (1d) dynamic training, and the number of completely correct constructed analogies at the transfer session (e.g., Tunteler & Resing, 2010). We did, however, expect to detect transfer of learning in analogical strategy use by closely considering the processes involved. Thus, we examined the individual transformations within the solved and constructed analogies, and also the children's subsequent accounts of these.

2. A second set of hypotheses concerned the number of transformations that were constructed correctly at the transfer session. Again, our expectations were related to our background variables. It was anticipated that children's employment of transformations in their constructed analogies would be related to (2a) spatial working-memory (Halford et al, 2010; Rasmussen & Bisanz, 2005), and (2b) their employment of transformations during their first session with the conventional analogical tasks (Bosma & Resing, 2006). When holding these background variables constant, we expected to find a relationship between children's progress in analogical strategy use through (2c) repeated practice, (2d) dynamic training, and the number of transformations they employed during the transfer session.

3. A third set of hypotheses concerned children's reflections on their analogical strategy use. We expected that children would be able to discuss and explain a greater number of transformations at the transfer session, if their accounts were also (3a) superior at the first session with conventional analogies, and their performance had improved as a result of (3b) repeated practice experience and (3c) dynamic training (Tunteler et al., 2008).

4. Our fourth set of hypotheses concerned children's qualitative reports of non-analogical, and analogical strategy use. We hypothesized (4a) that both children in the dynamic training condition, and those who were more successful in producing correctly constructed analogies, would cite analogical strategy use or offer their 'own rules' for incorrectly constructed analogies. We hypothesized (4b) that children in the practice condition who were unable to

construct any correct analogies would either provide ‘copy’ or ‘procedural’ explanations, or tell stories about the animals involved in their constructions. Furthermore we hypothesized (4c) that the transformations that would be explained most frequently would involve color, size and number. We expected the transformations, ‘orientation’ and ‘position’, to be explained less frequently, as these are seemingly more difficult to explain (Siegler & Svetina, 2002).

5.2 Method

Participants

Participants[3] (N=104; 51 boys; 53 girls) were aged 7-8 years with a mean of 93.6 months (*SD* = 4.8 months). They were selected from the second grade of eight regular primary middle-class schools located in the Netherlands. Parental informed consent was obtained for each participant.

Design

In an earlier study involving this sample (Pronk et al., submitted), each child’s inductive reasoning and working-memory capacity were assessed by means of an Exclusion test and a measure of spatial working-memory (see descriptions below). Subsequently, a microgenetic two-pretest-two-posttest control-group design was employed with randomized blocks based on the Exclusion test (see Table 1). After the fourth (final) session, both conditions received the same analogical construction task, which served to assess their breadth of cognitive change (transfer). It is this final stage that is the focus of this paper.

Table 1. Research design[1]

	Session						
Condition	Pretest	1	2	Training[2]	3	4	Transfer
Practice	x	x	x	-	x	x	x
DT	x	x	x	x	x	x	x

Note: [1]Sessions 1 to 4 were reported elsewhere (Pronk et al., submitted). The current study’s focus was transfer of cognitive changes induced by this type of design. [2]The practice-condition received the same items as the training condition, but the practice-condition received no dynamic-test-type training.

Instruments

Exclusion

Exclusion is a visual inductive reasoning subtest of a Dutch child intelligence test (RAKIT: Revisie Amsterdamse Kinder Intelligentie Test (Bleichrodt, Drenth, Zaal, & Resing, 1984). The subtest consists of 40 items each comprising 4 geometric figures. Three of the figures can

3 Participants include all participants of Chapter 4.

be grouped together on the basis of a rule that needs to be identified. The task requires the child to select the figure that, in each case, does not fulfill the rule.

Spatial recall

The Spatial recall test from the computerized Automated Working Memory Assessment (AWMA) battery (Alloway, 2007) was used to measure visual spatial working-memory capacity. The task involves recalling the positions of dots in relation to arbitrary shapes that rotate and/or flip from left to right.

Figural analogies

The analogical reasoning task consisted of an age-adapted version of the concrete figural analogies measure developed by Stevenson and Resing (e.g., Stevenson, Resing, & Froma, 2009; Stevenson, Touw, & Resing, 2011). The four practice sessions included four parallel sets with 20 open-ended 2x2 figural matrix analogies. The figures consisted of various permutations of six types of animals with three familiar colors, and two sizes; features that would be easily recognized by the participating children (Goswami, 1992). Items contained up to six transformations, involving size, color, number, orientation, position, and animal. Other than in the training session, the examiner provided minimal instruction, and this was unrelated to solving the analogies. After the production of each solution, the child was asked how he or she had solved the 'puzzle'.

Figural analogies dynamic-test-type training

The dynamic-test-type training material (Pronk et al., submitted), consisted of an age-adapted set of seven concrete figural analogy problems similar to those employed in the other sessions (these were adapted from Stevenson et al., 2009; 2011), and operated in accordance with Resing's (e.g., 1993) graduated-prompts dynamic test format. This approach has been successfully utilized in several previous studies (e.g., Resing, 2000; Resing & Elliott, 2011; Resing, Tunteler, de Jong, & Bosma, 2009; Resing, Steijn, Xenidou-Dervou, Stevenson, & Elliott, 2011, Resing et al., 2012). It utilizes a series of adaptive and standardized, hierarchically ordered, metacognitive (self-regulating) and cognitive prompts that proceed from general to task-specific. The prompts are provided only if the child is unable to proceed independently. Prompts become increasingly explicit, until the child arrives at the solution.

Our procedure involved the presentation of more challenging items from the beginning. While seemingly counter to usual practice, this has proven to be a helpful means of enabling even the most able performers to benefit from training from the outset. As a result, all the children in the sample are equipped to draw upon their newly learned strategies when tackling easier items (e.g., Resing, 1993; Resing & Elliott, 2011).

Construction tasks

The first analogical construction task included an A4-sized sheet displaying an empty matrix with four cells and baskets with all 72 animal cards. They were informed that they would now be the teacher and the examiner would take on the role of the child. The child was shown the empty matrix and told that this was an 'empty puzzle' in which he or she was allowed to make a puzzle using any of the cards for the examiner to solve, just like the puzzles the examiner had provided earlier. In this way, the child was able to spontaneously display his or her understanding of the tasks he or she had solved thus far.

Prior to commencing the other construction tasks, the examiner filled one of the cells of the matrix (the B or C cell) and the child was given the exact cards needed to create the puzzle for the examiner to solve. While the first construction task left freedom for the child to use any number and type of the 72 cards, the child was now given a restricted set of cards, all of which she or he was required to utilize for constructing 'the puzzle'. The restricted set of cards provided for these tasks were such that in order to utilize all the given cards *and* construct a correct analogy, the transformations number, color, and size, (and animal for the 3rd task only) needed to be included. By their own insight, children could opt to make the constructed analogies even more complex by choosing to flip the cards and/or position to include the transformations 'position' and 'orientation'.

For each of the tasks, the children were given as little instruction as possible in order to maximize spontaneous strategic analogical behavior. Some children, however, failed to start the task or forgot to leave one of the cells of the analogy open for the examiner to complete. In such situations, the child was given up to a maximum of 3 hints. Assistance was only given to help the child construct something that had the appearance of an analogy (with three filled and one empty cell) that the examiner could be asked to solve (see Appendix A for the procedure). After the child had finished creating the puzzle, the examiner placed down some random animal cards and asked a) if this was the correct answer, b) what was the child's correct answer, and c) why that was the correct answer. All explanations that the children gave about their analogy, including those that were provided before the examiner had asked for their explanations, were included in the scoring process.

Scoring

Table 2 provides the scoring system for the analogical measurements.

Table 2 Scoring system analogical measures

Score Type	Progress over time (Predictor Variables)	Measurement level	Transfer (Outcome Variables)	Measurement level
Complete Analogies Correct	Percentage of analogies that were completely and correctly solved during session 4 minus their score on session 1.	Ratio Scale; Scores could potentially range between 0-20.	The sum of correctly constructed analogical tasks (analogical tasks that were constructed in three terms, that could yield a full analogy if the right solution was created in the fourth empty term).	Ordinal Scale; Scores could potentially range between 0-3.
Transformations Correct	Percentage of correct transformations as evidenced by the child's behavioral solutions during session 4 minus their score on session 1.	Ratio Scale; Scores could potentially range between 0-110.	The sum of the transformations present within the correctly constructed analogical tasks. Transformations present in both the row and the column of the constructed analogical tasks were counted and summed up.	Count Data
Explained Transformations Correct	Percentage of correct transformations that children explained about their solutions during session 4 minus their score on session 1.	Ratio Scale; Scores could potentially range between 0-110.	The sum of correct transformations that children explained about the solutions to the analogical tasks they constructed. Explanations of correct transformations of all constructed analogical tasks were counted, whether the analogical task was completely correct or not.	Count Data
Implicit & non-analogical strategies[1]	N/A	N/A	The sum of each category (see Appendix B) a child mentioned when they subsequently explained the solution to their analogy.	Interval Scale; Scores per category could potentially range between 0-3.

Note: [1] If a child did not explicitly mention one or more correct transformations when explaining their solution to an item (or construction in the case of the reversal task), their explanation was not regarded as 'explicit analogical', but instead was categorized into one of seven 'explanation' categories (see Appendix B).

Analyses

The first outcome variable (Table 2) was an ordinal variable, violating the assumptions of least-squares regression. For this reason ordinal logistic regression was performed. (Agresti, 2007). The second and third outcome measures were specified as counts (Table 2). An appropriate regression analysis for this class of data is Poisson regression, of which type we performed a negative binomial regression. (Agresti, 2007). All regression analyses were run with successive nested models that each included an additional expected variable. These nested models were compared with a likelihood ratio test to determine if the succeeding model – and therefore the added predictor – presented a significantly better fit than the previous one (Agresti, 2007). For each outcome measure we first included the background variables (working-memory and/or initial capacity) in the models, after which the variables of main interest were included: progress in analogical performance and condition.

For the qualitative analyses, the focus was on the strategies that children described when discussing how they solved each of their 'puzzles' (see Appendix B), and their accounts of the type and number of transformations at the transfer session.

5.3 Results

Before conducting the regression analyses, we checked for possible initial differences between the dynamic test and practice conditions. The mean scores on the Exclusion test did not differ significantly, nor did the mean number of complete analogical solutions, transformations or explanations at session one. Means and standard deviations for the analogical measurements utilized in this study are provided in Table 3.

Table 3. Means and standard deviations of analogical measurements

Condition	Progress over time[1] Mean (SD)	Transfer Session Mean (SD)
	Correct Solutions	
Practice (N=52)	11.06 (15.16)	.67 (.88)
Dynamic Training (N=52)	22.60 (20.73)	.73 (.89)
Total (N=104)	16.83 (18.89)	.70 (.88)
	Transformations Correct	
Practice (N=52)	6.28 (11.88)	3.13 (4.53)
Dynamic Training (N=52)	18.36 (20.98)	3.60 (4.54)
Total (N=104)	12.32 (18.02)	3.37 (4.52)
	Explained Transformations	
Practice (N=52)	.81 (10.55)	1.44 (1.93)
Dynamic Training (N=52)	7.20 (15.69)	2.02 (2.42)
Total (N=104)	4.00 (13.68)	1.73 (2.20)

[1]Progress over time is given in percentages.

Regression analyses with likelihood ratio tests

To investigate our first set of hypotheses concerning the number of correctly constructed analogies at the transfer session (ranging 0-3), we performed ordinal logistic regression analyses with five successive models (including the intercept only model, see Table 4). The best fitting model – Model 3 in Table 4 – confirmed our expectations that children would construct more correct analogies at the transfer session if at the start of the study they demonstrated (1a) superior spatial working-memory (β=.02, p=.03), and (1b) a higher score for the analogical tasks (while holding spatial working-memory constant) (β=.05, p<.001). The final two models – Models 4 and 5 in Table 4 – did not prove to be a significant improvement to our first models. This confirmed our expectation that we would be unable to detect a relationship between progress in the number of correct solved analogical tasks following (1c) repeated practice experience (β=.02, p=.19), or (1d) dynamic training and the number of correctly constructed analogies at the transfer session (while holding spatial working-memory and initial performance constant) (β=-.03, p=.96).

Table 4. Results of the likelihood ratio tests for the nested models

Outcome measure of the transfer session	Model Progression[1]	Likelihood Ratio test		
		Likelihood Ratio[2]	*DLR*[3]	*P*
Analogies constructed completely correct[4]	1. Intercept only (Null)	0	-	-
	2. + Working Memory Spatial Span	19.94	19.94*	< .001
	3. + Initial Capacity[6]	**45.72**	**25.78***	**< .001**
	4. + Progress in analogical performance	47.56	1.85	.17
	5. + Condition[4]	47.57	.01	.92
Transformations present in complete analogies[5]	1. Intercept only (Null)	0	-	-
	2. + Working Memory Spatial Span	15.62	15.62*	< .001
	3. + Initial Capacity	75.14	59.52*	< .001
	4. + Progress in analogical performance[6]	**79.77**	**4.63***	**.03**
	5. + Condition[4]	79.79	.02	.89
Explained transformations[5]	1. Intercept only (Null)	0	-	-
	2. + Initial Capacity	18.52	18.52*	< .001
	3. + Progress in analogical performance[6]	**25.25**	**6.73***	**.009**
	4. + Condition	26.10	.85	.36

** Significantly better fit than former models at p ≤ .05; [1]Each successive model included one additional predictor and the former model was nested within the succeeding model. [2]The likelihood ratio chi-square is the difference between the -2 log likelihoods of the intercept-only and the current model. [3]DLR is the difference in the Likelihood Ratio statistics of two nested models and is a statistical test for the variable that enters the model. [4]Ordinal regression with nested models compared with a likelihood ratio test. [5]Negative binomial regression compared with a likelihood ratio test. [6]Bold = this was the final model as the additional effect included in this model was the last one to further improve the model.*

To investigate our second set of hypotheses concerning the number of transformations included in the correctly constructed analogies (observed range: 0-17) at the transfer session, negative binomial regression analyses were utilized. Again, five successive models were run and compared to each other using a likelihood ratio test (see Table 4). Model 2 confirmed hypothesis 2a, concerning working-memory capacity. However, the best fitting model was Model 4, where working-memory no longer contributed significantly (β=.01, p=.22). Model 4 did confirm our expectations that children would use more transformations in their constructed analogies at the transfer session if they initially utilized more transformations at the first practice session (β=.05, p<.001) (hypothesis 2b). Model 4 also confirmed hypothesis

2c, which anticipated a positive relationship between children's progress in analogical strategy use through repeated practice experience over time, and the number of transformations these children used within their correctly constructed analogies at the transfer session (β=.02, p=.03) (again, while holding spatial working-memory and initial capacity constant). Model 5 (Table 4) included the condition variable, but unexpectedly this model was not a significant improvement upon the former model. This, therefore, failed to support hypothesis 2d, which anticipated a positive relationship between the dynamic-test-type training and the number of transformations children used within their correctly constructed analogies at the transfer session (while holding the former significant effects constant).

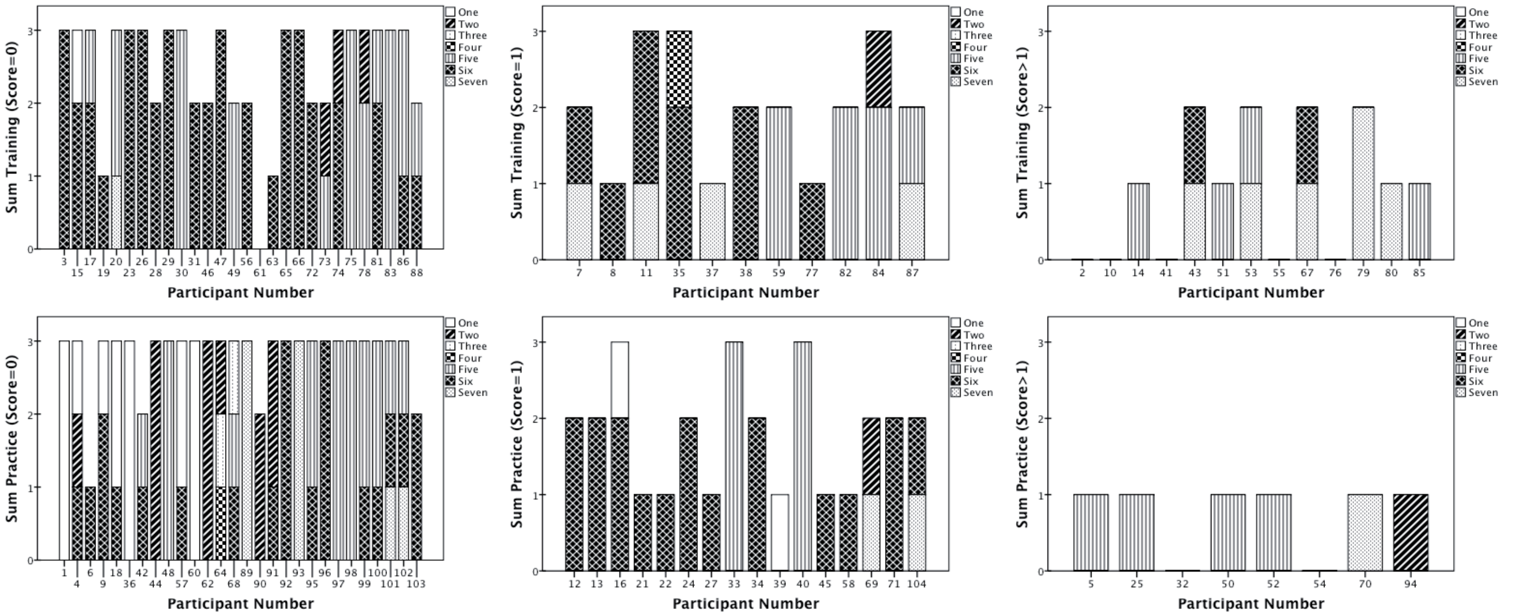
To investigate our third set of hypotheses concerning the number of transformations explained correctly after each construction task had been completed (observed range: 0-10), negative binomial regression analyses were utilized. Four successive models were run and compared with a likelihood ratio test (see Table 4). The best fitting model, Model 3, confirmed our expectations that children would provide explanations indicating superior analogical strategy use at the transfer session if they had performed well at the first session (β=.03, p<.001) (hypothesis 3a), and if they had made progress explaining analogical strategies during the practice sessions (β=.02, p=.01) (hypothesis 3b).

Model 4 (Table 4) included the condition variable, but unexpectedly this was not a significant improvement upon the former model, and, therefore, did not support hypothesis 3c.

Qualitative investigations

To investigate our fourth set of hypotheses, we explored children's statements about their strategy use (see Figures 1-3). Figure 1 displays explained strategy use per constructed analogy of 'subgroups' of children based on condition and their number of correctly constructed analogies at the transfer session.

Figure 1. Solution strategies (non-analogical and implicit analogical) explained per child and condition, divided by the number of correctly constructed analogies: 0 correct, 1 correct, and more than 1 correct. Strategies[1]: 1=copy; 2=part copy; 3=procedural; 4=story; 5=don't know; 6=own rule; 7=implicit analogical. *The (partial) absence of a bar represents verbalizations including at least one correct transformation.*



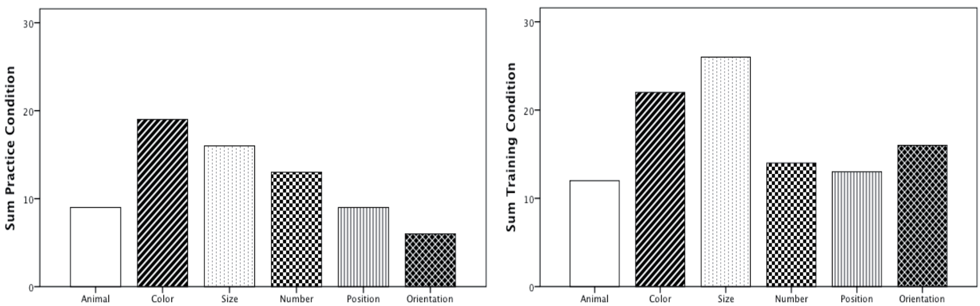
Note: [1]a more elaborate description can be found in Appendix B. The group of children with zero correctly constructed analogies displayed the greatest variation between conditions in their strategy use. Children in the training condition displayed more explicit analogical strategy use, and more of their 'own rules' than the practice condition. Moreover, the training condition displayed hardly any 'copy' strategies, while the practice condition displayed a considerable amount of 'copy' strategies. The children with one correctly constructed analogy tended to use – in both conditions – the same non-analogical strategies ('own rule' and 'don't know'), besides implicit and explicit analogical strategies. The group of children with more than one correctly constructed analogy mainly used explicit analogical strategies, beside some 'don't know' and implicit analogical strategies.

Overall, children in the training condition constructed 'more than one correct analogy' more often than just 'one correct analogy', while the practice condition showed the opposite. Hypothesis 4a was confirmed (see Figure 1).

Hypothesis 4b was partially confirmed. As expected, children in the practice condition who were unable to construct any correct analogy provided more 'copy' explanations. However, contrary to our expectations, they often also included their own rules and hardly ever told stories about the animals or gave procedural information, as they had done after solving the traditional analogical tasks (Pronk et al., submitted).

We also hypothesized (4c) that transformations would be explained most frequently by reference to color, size and number. We expected the more challenging transformations, 'orientation' and 'position', to be identified less frequently. Figure 2 demonstrates that, indeed, this pattern was found for the practice condition.

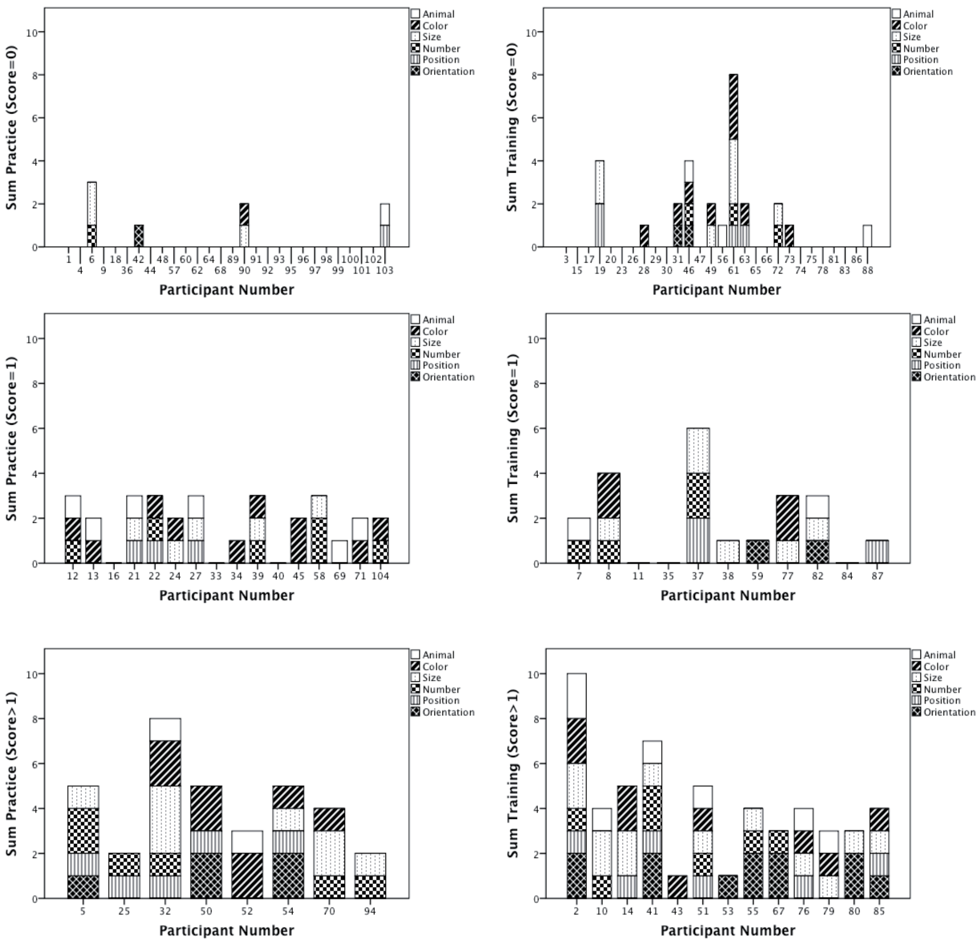
Figure 2. Type and number of transformations explained at the transfer session by condition



The results for the training condition were somewhat different, however (see Figure 2). Here, children explained more transformations and made more frequent references to the 'more difficult' transformations (orientation and position).

Figure 3 offers a more in-depth look at the distributions displayed in Figure 2. Here, it can be seen the subgroups of children presented in Figure 1, which were based on condition and their number of correctly constructed analogies at the transfer session.

Figure 3. Type and number of transformations explained per child by condition and number of correctly constructed analogies: 0 correct, 1 correct, more than 1 correct.



The largest differences are those between the lowest and highest performing subgroups. In the former, where children were unable to construct a complete analogy, several children from the training condition, but none from the practice condition, were able to display or explain analogical strategy use. In the latter, where most children were from the training condition, a larger variety of explained transformations per child were evident.

5.4 Discussion

In this study we sought to assess the depth and breadth of changes in analogical performance, induced by either a dynamic test-type-training or repeated practice experiences. Although initial performance and progress on traditional analogical tasks predicted how well children would fare on the self-construction analogy task, it was the children's partial performance (such as use of only a single transformation), rather than complete solutions, that was the key predictor. 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).

The analogy construction tasks in the current study, especially the more complex ones, were difficult to fully master in such a relatively short study period (Tzuriel & George, 2009), particularly for children of this age (Halford & McCredden, 1998). It was notable that partial construction scores were important even after initial capacity and working-memory had been held constant. Clearly, we can conclude that the capacity to solve analogies is related to the capacity to construct them (see also, Harpaz-Itay, Kaniel, Ben-Amram, 2006; Bosma & Resing, 2006). The relationship we found between spatial working-memory and analogy construction confirmed earlier studies as well (e.g., Rasmussen & Bisanz, 2005; Tunteler et al., 2008; Halford et al., 2010). Unsurprisingly, children were better constructors when they executed their analogical strategies (more) efficiently (Siegler, 2006). These outcomes indicate that those who progressed further with the construction tasks, acquired a more thorough or 'deeper' understanding of the underlying principles involved. After all, while constructing analogy tasks, children needed to extract the earlier learned analogical relationships from schemas in their memory, rather than working out existing relationships in the tasks presented to them (Perkins, 1992; Harpaz-Itay et al., 2006; Martinez, 1999).

It is interesting that the dynamic-test-type training appeared to provide no additional improvement in task performance over that of repeated practice alone. Perhaps, for a quantitative effect to emerge, the training will need to be rendered more extensive by adding more items or an extra session in between the final practice sessions (e.g., Tzuriel & George, 2009).

Children in the training condition explained a greater percentage per possible transformation and were more likely to refer to the more difficult types of transformations: orientation and position (Siegler & Svetina, 2002; Stevenson et al., 2011). While this was a specific feature of high achievers, it was noticeable that this also applied to poorer performers. Apparently, even many of them had understood and retained several of the taught analogical relationships, and were able to successfully access, apply and cite these (Harpaz-Itay et al., 2006). Furthermore, although the greater number of fully correct analogies produced by children in the training condition *at the transfer stage* was not statistically significant, they often provided qualitatively different explanations for these solutions. Where their constructed analogy was incorrect, they obviously had created their own rules. They rarely demonstrated the more simple solution strategies that complete novices often show, such as mere copy strategies, as was the case for many of the children in the practice condition (Sternberg & Rifkin, 1979; Siegler & Svetina, 2002). The evidence from the qualitative part of our investigation suggests that training was having an effect on the breath of change, but the training procedure may need to be more substantial for quantitative differences to become possible to emerge.

Although many children in the practice condition cited copying strategies for solving their self-constructed analogies, they also often included their own rules and, in contrast with the earlier assessment sessions, rarely reverted to storytelling or procedural strategies. It is possible that multiple choice, and even constructed response analogical task formats, encourage children to adopt strategies such as copying and storytelling (Martinez, 1999; Stanger-Hall, 2012; Morrison, Doumas, & Richland, 2011). However, a more empty task, such as the one used in this study, may encourage the deployment of more creative solutions.

Future studies should investigate whether creative solutions of this nature, garnered from either dynamic testing or practice situations, are able to provide additional data about the child's developing problem solving capacities.

In the somewhat different domain of science, creative reasoning, where children generated self-made analogies during their lessons, has been found to be an important precursor in their understanding of natural phenomena, (e.g., Pittman, 1999; May, Hammer, & Roy, 2006; Haglund, Jeppsson, & Anderson, 2012). These self-generated analogies revealed children's previously acquired knowledge and experience, and appeared to encouraged them to process the material deeply and consequently gain understanding of underpinning structural relations (e.g., Blanchette & Dunbar, 2000; Harpaz-Itay et al., 2006). Assessment of children's constructed analogies, using non-academic, domain general tasks, such as those used in the present study, could possibly reveal their current depth of general understanding of the complexity of analogical strategies. Examining children's differential responses to training and practice on analogy construction tasks has the potential to offer educational psychologists and teachers additional insights into the stability of the individual's reasoning processes.

The current study has shown that an analogical construction task, serving as a measure of transfer, can provide additional information about young children's depth of learning and learning potential. Such information, perhaps in combination with working-memory assessment data (Alloway, Gathercole, & Pickering, 2006; Alloway & Gathercole, 2006; St. Claire-Thompson & Gathercole, 2006), may prove to be of practical benefit to teachers (May et al., 2006), although more research is needed to justify such a claim. More specifically, this study suggests that knowledge of the types of strategies children utilize and verbalize can yield insights and understanding about (individual) children's readiness for learning. Such a conclusion has important implications for both individual and larger scale educational dynamic-test situations and particular curricula areas (e.g., Grigorenko, 2009; Haglund et al., 2012), for example in science education or math. Whether analogical construction tasks provide more valuable information to educationalists when these are domain specific (e.g. relating to math or science content) or domain general, such as the task reported in the present study, is a question that requires further investigation.

Appendix A

Hint procedure for the transfer tasks

Nr	Hint	Procedure
1	[*If* a child does not get started proceed with the first hint.] What was it that you needed to do? First you choose (animal) cards for the first two cells, for example for these two (point to A & B cells) or for these two (point to A & C cells), and you lay down these cards. Do you remember now?	If the child gets started, no more hints are provided until cards have been laid down in three of the four cells of the matrix. Otherwise proceed to the next hint.
2	After that, you think about which cards you want to put into the last two cells, so that everything goes together. Do you remember now?	Same as above.
3	Then you put down the cards for the third cell and you leave the last cell open. After that you may tell me what I need to do.	If a child is still unable to construct something that looks like an open-ended figural analogy, move on to the next task.

Note: Children were given up to three hints (if needed), so that 'their puzzle' looked like the open-ended figural analogies that they had solved during the practice and dynamic training sessions. Hints were only provided to help a child get started if he/she didn't start on their own. Hints were not provided to explain how a proper analogy should be constructed.

Appendix B

Scoring system of the figural analogies

Category[1]	Description	Example
1. Copy	The child indicates that their solution is a copy of another cell of the analogy.	'It's this one', while pointing to another cell of the analogy.
2. Part copy	The child indicates that s/he has copied part(s) of other cell(s), and the behavioral solution confirms this.	'I took that one and that one, but not that one', while pointing to specific animals relating to another cell.
3. Procedural	The child gives simple information about picking up particular animal cards and putting them in the empty cell.	'I picked up this card and put it down here. I also wanted to lay down this one, but it didn't fit.'
4. Story	The child tells a story about the animals.	'This horse likes that one and this is the mummy and that is her baby.'
5. Don't know	The child indicates ignorance as to how he or she solved the puzzle.	'I don't know', 'I guessed', 'I just liked it.'
6. Own rule	The child indicates that s/he made up a rule and applied it to the analogy. However, this isn't a correct transformation.	'I made this one blue, because there was no blue yet.' Or: 'One bear plus one, so this one needs two.'
7. Implicit analogical	Correct transformations are clearly present in the behavioral solution, but the child only refers to them implicitly.	'I made it just like there,' while pointing to the top two cells and then to the bottom two cells.

Note: [1]Categories were created in accordance with children's answers and partially derived from the work of others (e.g., Siegler & Svetina, 2002; Tunteler et al., 2008).

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.

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Nederlandse samenvatting

(Summary in Dutch)

Binnen de schoolpsychologie vindt een belangrijk debat plaats over het nut van cognitieve tests voor het inzetten van educatieve interventies. In de ogen van veel orthopedagogen en psychologen hebben psychometrische instrumenten hun nut bewezen voor het doel van selectie. Toch bieden deze instrumenten nog onvoldoende mogelijkheden aan leerkrachten als het gaat om het maken van goede beslissingen met betrekking tot educatieve interventies voor individuele kinderen. Het is daarom van belang om in detail individuele leertrajecten te onderzoeken, zodat vernieuwender vormen van instructie en educatieve interventies kunnen worden ontwikkeld. De aanpak in de huidige dissertatie had als doel hiertoe een aanzet te geven.

Leertrajecten voor het oplossen van cognitieve taken werden onderzocht door veranderingen in het strategiegedrag van groepen en individuele kinderen in kaart te brengen. Hierbij werd voornamelijk analogisch probleemoplossend strategiegedrag onderzocht, zoals jonge kinderen in de leeftijd van zes tot acht jaar dit laten zien. Dit type probleemoplossend redeneren wordt als een belangrijke bouwsteen voor de cognitieve ontwikkeling van academische, analytische intelligentie gezien.

Het woord analogie komt van het Griekse woord *ana logon:* volgens de ratio, volgens het menselijk denkvermogen. Aristoteles verwoordde de analogie als: “Zoals A staat tot B, zo staat C tot D” en “Zoals A is in B, zo is C in D” (Encyclopaedia Brittanica, 2002). Een voorbeeld hiervan is: “Zoals een deur staat tot een huis, zo staat een poort tot een stad” en “Zoals een deur is in een huis, zo is een poort in een stad.” De basis voor het zien van dergelijke relaties is volgens diverse onderzoekers al aanwezig op heel jonge leeftijd (Goswami, 1992). Met name de eerste jaren van de basisschool worden gezien als een belangrijke periode voor de ontwikkeling van analogisch redeneren en worden in de literatuur dan ook beschouwd als cruciaal om leerprocessen met betrekking tot analogisch redeneren in kaart te brengen (e.g. Tunteler & Resing, 2007a).

De studies in deze dissertatie werden derhalve ontworpen om gedetailleerd inzicht te verschaffen in de leerprocessen van jonge kinderen met betrekking tot analogisch probleemoplossend strategiegedrag. Kinderen kregen herhaaldelijk complexe analogietaken aangeboden zonder hulp en/of met hulp, waarna hen in een van de studies werd gevraagd om zelf (complexe) analogietaken te maken. Zowel kwalitatieve als kwantitatieve analysemethoden werden gebruikt om bovenstaande leerprocessen en daarmee samenhangende leertrajecten in analogisch strategisch redeneren zichtbaar te maken.

In **hoofdstuk 1** werden de theoretische en methodologische achtergronden van de studies in deze dissertatie besproken. De rode draad in dit hoofdstuk was de microgenetische onderzoeksmethode die berust op de ideeën van Werner en Vygotsky en meer recentelijk is geadopteerd door onder andere Siegler (1991). Dit is een methode waarbij in korte tijd verscheidene herhaalde metingen verricht worden bij dezelfde proefpersonen. Zodoende kunnen (kleine) veranderingen in gedrag tussen metingen, binnen en tussen proefpersonen, nauwkeurig vastgelegd worden. Video- opnamen, zoals gebruikt in deze dissertatie, bleken uitermate geschikt om achteraf op gedetailleerde wijze (kleine) strategieveranderingen in kaart te brengen. Dit gaf als het ware een close-up van de veranderingen in de loop van de tijd. Zo werden in de huidige dissertatie de leertrajecten van individuele kinderen, maar ook van groepen kinderen met gelijksoortige leertrajecten nauwgezet bestudeerd. Siegler (1996) beschreef de bevindingen van studies die gebruik maakten van deze onderzoeksmethode in zijn 'Overlapping Waves' theorie over cognitieve verandering. Deze theorie beschrijft vijf dimensies van cognitieve verandering in de loop van de tijd: de oorzaken van verandering, de snelheid van verandering, de breedte/diepte van verandering, de variabiliteit van verandering en het traject van verandering. Op deze aspecten van verandering werd in het eerste hoofdstuk dieper ingegaan.

Naast veranderingen in analogisch probleemoplossend strategiegedrag door herhaalde oefenmomenten, waarbij kinderen geen hulp aangeboden kregen, werden ook strategie-veranderingen na interventies in kaart gebracht. Interventies bestonden uit dynamische tests/trainingen. In tegenstelling tot traditionele 'statische' tests krijgen kinderen bij dynamische tests, mocht dit nodig zijn, feedback en hints bij het maken van de opgaven (Resing, 1993; Elliott, 2003; Grigorenko, 2009). Het is de bedoeling van deze vorm van testen om op deze manier de meest geschikte persoonlijke hulp te geven om de opgaven zo goed en snel mogelijk te maken. Dynamische tests kunnen zodoende het type en de hoeveelheid benodigde hulp in kaart brengen, hetgeen meer inzicht verschaft in het potentieel tot leren en de mogelijke specifieke educatieve behoeften van het individuele kind. Dynamische tests richten zich derhalve op datgene wat het kind zou kunnen wanneer hij of zij de juiste hulp krijgt. Traditionele tests, daarentegen, richten zich op datgene wat het kind al kan en geleerd heeft tot op het moment van de test (Grigorenko, 2009).

Om de individuele verschillen in leertrajecten van kinderen zo goed mogelijk zichtbaar te maken, werden specifieke data-analyse methoden gebruikt, waaronder Multilevel Analysis. Normaal gesproken wordt Multilevel Analyse ingezet voor data met verschillende niveaus: zogenaamde 'Levels' (Hox, 2010). Dergelijke niveaus kunnen bijvoorbeeld bestaan uit kinderen binnen scholen, scholen binnen schoolregio's, en regio's binnen landen. In hoofdstukken drie en vier werd deze methode echter op een alternatieve manier ingezet, door de bovengenoemde herhaalde meetmomenten binnen kinderen te laten vallen (in plaats van kinderen binnen bijvoorbeeld scholen). Derhalve konden algemene leertrajecten van verschillende groepen kinderen gemodelleerd worden, maar ook de leertrajecten van de individuele kinderen binnen deze groepen.

In **hoofdstuk 2** werden variatie en veranderingen in analogisch probleemoplossend strategiegedrag bij kinderen uit groep drie in kaart gebracht. In de eerste fase van dit onderzoek kregen kinderen enkel oefenopgaven met geometrische figuren, zonder uitleg of feedback. Na twee sessies met oefenopgaven kreeg de helft van de kinderen een korte dynamische training. Vervolgens kregen alle kinderen nog drie sessies met enkel oefenopgaven. Uitkomsten van dit onderzoek gaven een close-up van variabel strategiegedrag binnen individuele, alsmede binnen groepjes kinderen. Zo werd zichtbaar dat herhaald oefenen met analogietaken, zonder uitleg of feedback, bij sommige kinderen reeds een spontane verbetering in analogisch redeneren teweeg bracht. Deze verbetering werd voornamelijk zichtbaar bij kinderen die aan het begin van de studie gedeeltelijk analogisch strategiegedrag vertoonden, maar vervolgens (meer) volledig analogisch strategiegedrag ontwikkelden. De korte dynamische training bracht echter een grotere verbetering in analogisch strategiegedrag teweeg. Na training ontwikkelden sommige kinderen, die daarvoor nog geen analogisch strategiegedrag vertoonden, dit gedrag op een wat 'abrupte' en snelle manier. Andere kinderen, die daarvoor al wel enig analogisch strategiegedrag vertoonden, ontwikkelden dit strategiegedrag wat meer geleidelijk, tijdens zowel de oefensessies als tijdens de training. Daarnaast bleek de training invloedrijk voor de vaardigheid van kinderen om dit analogisch strategiegebruik expliciet te kunnen benoemen, nadat de onderzoeker hiernaar vroeg. Bovengenoemde effecten werden na drie maanden nogmaals gemeten en werden op dat moment zelfs nog duidelijker zichtbaar.

In **hoofdstukken 3 en 4** werden de variatie en veranderingen in analogisch probleemoplossend strategiegedrag bij kinderen uit groep vier in kaart gebracht. Deze kinderen kregen geen geometrische, maar matrix analogietaken met dierenfiguren. Multilevel Analyse werd ingezet om leertrajecten in analogische redeneren zichtbaar te maken bij subgroepen en individuele kinderen. Kinderen werden in subgroepen ingedeeld op basis van conditie (wel of geen training) en mogelijk invloedrijke variabelen, zoals werkgeheugenprestaties. Uitkomsten lieten zien dat leertrajecten van kinderen binnen subgroepen meer op elkaar leken dan leertrajecten tussen subgroepen. Zo bleek een dynamische test/training het analogisch strategiegebruik meer te verbeteren dan alleen herhaald oefenen (zonder hulp of feedback).

Daarnaast was het ruimtelijk-visueel werkgeheugen invloedrijk bij het analogisch strategiegedrag aan het begin van de studie. Dit analogisch strategiegedrag aan het begin van de studie vertoonde vervolgens een relatie met meer analogisch strategiegebruik en uitleg tijdens de vervolgsessies, bij kinderen die later geen training kregen. Bij kinderen die wel training kregen, werd na de dynamische test/training, zowel meer variatie in typen strategiegedrag, als meer analogisch strategiegebruik gevonden. Zo creëerden getrainde kinderen, wanneer zij de analogietaak (deels) niet-analogisch oplosten, regelmatig hun eigen (niet-analogische) oplossingsregels in plaats van simpele kopieerstrategieën te gebruiken. Zij gaven bijvoorbeeld aan dat zij een bepaalde telling van de dieren hadden gemaakt, of naar bepaalde kleuren hadden gekeken (op een niet/ (pre-)analogische manier).

Het op deze manier vergelijken van de leertrajecten tussen subgroepen was veelbelovend om zicht te krijgen op specifieke sterkten en zwakten van deze trajecten. Mogelijk kunnen in de toekomst gespecialiseerde educatieve interventies ingezet worden voor individuele kinderen met specifieke sterkte- en zwakteprofielen, zoals gevonden bij de leertrajecten in huidig onderzoek. Toekomstige studies zal de mogelijkheden voor dergelijke educatieve interventies moeten onderzoeken.

In **hoofdstuk 5** vond onderzoek plaats naar de diepgang van het groeiproces in (analogisch) strategiegedrag bij kinderen uit groep vier, zoals gevonden in hoofdstukken 3 en 4. Kinderen werd gevraagd om puzzels (analogietaken) te maken voor de onderzoeker, net zoals de puzzels (analogietaken) die de onderzoeker voor hen had gemaakt. Kinderen kregen daarbij enkel de materialen aangeboden om de puzzels te maken. Zij kregen verder geen inhoudelijke uitleg hoe zo'n puzzel gemaakt kan worden. Resultaten van dit onderzoek wezen uit dat aanvankelijk analogisch strategiegebruik van kinderen (zoals beschreven in hoofdstukken 3 en 4), alsmede hun ruimtelijk-visueel werkgeheugen van invloed zijn op de juistheid en de moeilijkheidsgraad van de puzzels die door deze kinderen werden gemaakt. Daarnaast bleek dat kinderen die de meeste groei in analogisch strategiegebruik hadden doorgemaakt tijdens het oplossen van de eerder aangeboden analogieën, ook de meeste (complexe) analogieën konden creëren. Kinderen die daarnaast ook een dynamische test/ training in het oplossen van analogieën hadden gehad, konden de (analogische) relaties binnen hun zelfgemaakte analogieën beter benoemen. Een dergelijke 'constructietaak' lijkt derhalve belangrijke informatie te verstrekken over de diepgang van strategieveranderingen in analogisch redeneren, die plaatsvindt in kinderen tijdens en na statische en dynamische testsituaties.

In **hoofdstuk 6** werden de uitkomsten van voorgaande hoofdstukken besproken aan de hand van de eerder genoemde 'Overlapping Waves' theorie, met haar vijf dimensies van cognitieve verandering (Siegler, 1996). Er werd geconcludeerd dat er veel variatie en variabiliteit in analogisch strategiegedrag was gevonden tussen subgroepen kinderen onderling, alsmede binnen de individuele kinderen zelf. Hierbij werden specifieke leertrajecten zichtbaar, die een verscheidenheid aan cognitieve sterkten en zwakten vertoonden. Deze uitkomsten leken waardevol te zijn voor zowel de algemene kennis van de ontwikkeling van analytische intelligentie, als voor het voorspellen van individuele leertrajecten bij jonge kinderen. Uitkomsten zouden van nut kunnen zijn voor het ontwikkelen van gespecialiseerde educatieve interventies, die ingezet kunnen worden in een vroeg stadium, wanneer een kind deze hulp nodig lijkt te hebben.

Dynamische tests zouden in de toekomst kunnen uitwijzen dat bepaalde vormen van instructie het meest effectief ingezet kunnen worden bij kinderen met een daarbij passend leerprofiel. De mogelijkheden en beschikbaarheid van dergelijke educatieve interventies binnen het huidige schoolsystem is echter nog erg beperkt.

Uit de huidige dissertatie kwam naar voren dat verschillende bronnen van informatie nodig zijn voor het ontwikkelen van holistische en specifieke cognitieve tests en educatieve interventies. Het bleek dat een combinatie van analogietaken, waarbij kinderen zelf de oplossing moesten samenstellen, met daarnaast een dynamische test en een constructietaak, gevoelig was voor ieder niveau van cognitief functioneren van de betrokken kinderen. Daarbij bleek het gebruik van verschillende analogische *en* niet-analogische uitkomstmaten een belangrijke bron van voorspelling van individuele leertrajecten. Binnen deze trajecten konden momenten geïdentificeerd worden waarop kinderen met bepaald strategiegedrag mogelijk meer of minder gevoelig waren voor verschillende typen instructie.

Deze uitkomsten suggereren dat in de toekomst leertests gevoelig(er) moeten worden voor gedeeltelijk correct en zelfs ontoereikend strategiegedrag. Zo kan een kind aanvankelijk één ontoereikende strategie gebruiken en vervolgens, naar aanleiding van training, een verscheidenheid van ontoereikende strategieën toepassen. Hoewel het kind, na training, nog geen correct strategiegedrag vertoont, is dit type van variabel strategiegedrag mogelijk wel een voorstadium daarvan (Siegler, 2007), zoals ook gemeten werd door Siegler en Svetina (2004). Wanneer enkel correct strategiegedrag gemeten zou worden, zou deze mogelijk positieve verandering onder invloed van training onopgemerkt blijven. Derhalve zouden er verkeerde conclusies getrokken kunnen worden met betrekking tot het leerpotentieel en de mate waarin het kind getraind kan worden.

Ook is het bijvoorbeeld mogelijk dat kinderen, die hun eigen regels creëren om analogietaken 'op te lossen', zich in een verder gevorderd voorstadium van correct strategiegedrag bevinden en daarbij andere instructie behoeven dan kinderen die enkel kopieerstrategieën laten zien.

Tenslotte zou het aantal en het type (analogische) relaties dat een kind gebruikt bij het oplossen en creëren van analogieën een goede maat kunnen zijn voor het differentiëren tussen kinderen met een grotere cognitieve capaciteit. Vooral bij constructietaken komt dit helder tot uitdrukking, omdat het kind niet meer kan steunen op datgene wat hij of zij voor zich ziet liggen. Vanuit het eigen (werk)geheugen van het kind en de eigen kennisbasis moeten relaties gecreëerd worden die samen een correcte analogie vormen. Het aantal (analogische) relaties dat een kind aan een dergelijke zelfgemaakte analogie toevoegt, alsmede het type relatie dat het kind gebruikt, zijn goede maten om onderscheid te maken tussen kinderen met minder en meer geavanceerd analogisch strategiegedrag.

Toekomstig onderzoek moet de huidige uitkomsten verifiëren. Uitkomsten kunnen vervolgens gebruikt worden voor de ontwikkeling van een vernieuwende testbatterij die cognitieve intelligentie en leerpotentieel breder kan meten. Een dergelijke testbatterij zou meer specifieke informatie kunnen verschaffen voor mogelijk noodzakelijke educatieve interventies bij individuele kinderen. Daarnaast kunnen uitkomsten van huidig en toekomstig onderzoek gebruikt worden om dergelijke educatieve interventies te ontwikkelen.

Curriculum Vitae

Christine Pronk was born on March 31, 1980, in Amersfoort, the Netherlands. She obtained her high school diploma in 1998 from Randmeer College in Harderwijk.

In 2003 she enrolled at Leiden University to study Psychology. In her third year, she undertook an individual honors research bachelor project under the supervision of Dr. Erica Tunteler and Professor Wilma Resing. She utilized the microgenetic research method to investigate children's potential to reason by analogy. This project led to her first publication.

After obtaining her BSc degree in Psychology with honors in 2006, she enrolled in the Leiden University Research Master in Psychology with the track 'Child Development and Psychopathology'. For her research internship, Professor Joe Elliott welcomed her at the School of Education at Durham University in the United Kingdom. Here she participated in several inspiring research projects about working memory and ADHD, and giftedness in children (the Aurora project from Yale University, USA). For her master thesis, under supervision of Professor Wilma Resing, she further investigated young children's capacity to reason by analogy in combination with their working memory performance.

At this time, she also began working full time at a Juvenile Justice Institute. At this institute, she first worked as a pedagogical worker with delinquent teenagers with a mild mental handicap, and later as a research assistant at a mental health screening and diagnostics project.

She obtained her MPhil degree in Psychology in 2010, and remained at Leiden University as an external PhD candidate at the Dynamic Testing Lab under supervision of Professors Wilma Resing (Leiden University) and Joe Elliott (Durham University). At the same time, she continued to work full time at the Juvenile Justice Institute for the Academic Workplace Forensic Care for Youth. Currently, she continues to work there as an executive researcher for projects involving Routine Outcome Monitoring, neuropsychology and the validation of mental health screening instruments.