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

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CHAPTER 4

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

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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 $p \leq .05$; [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 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

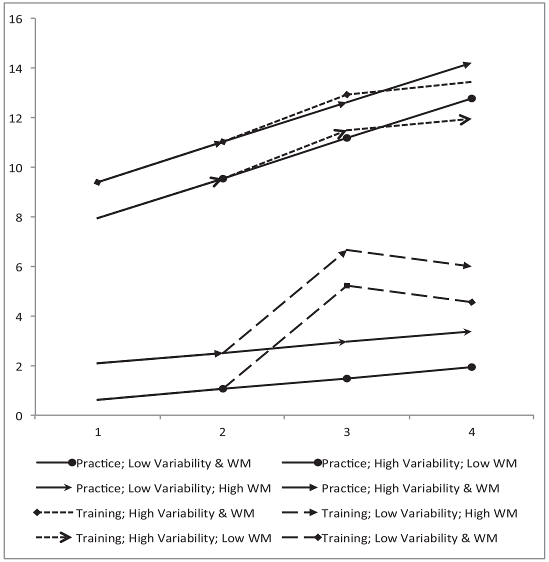


Figure 2. Regression lines for explained transformations for the eight subgroups

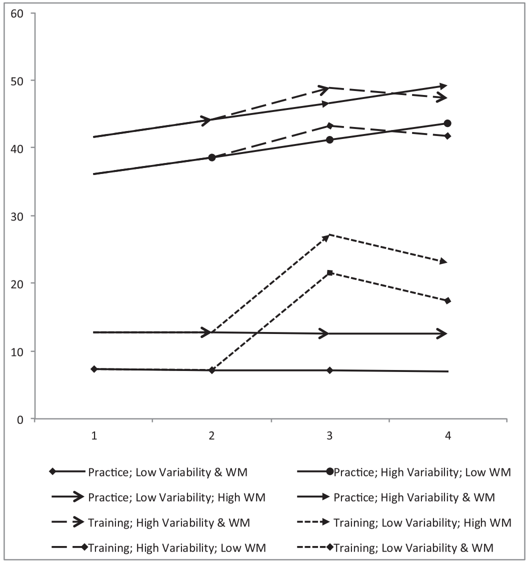
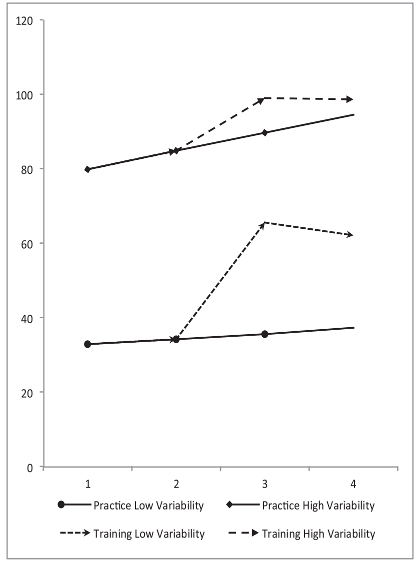


Figure 3. Regression lines for correct transformations for the four subgroups



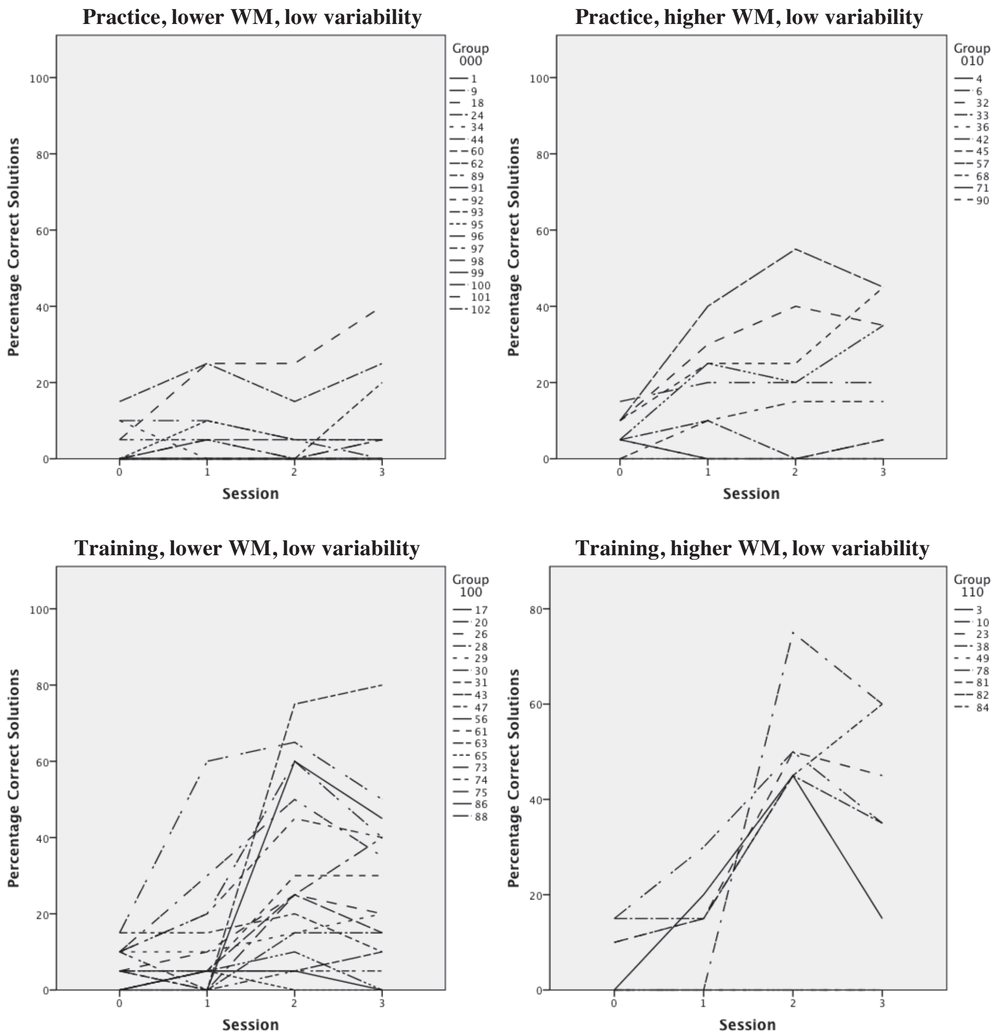
For our first outcome measure – the number of completely correct analogical solutions – model 10 (see Table 4) proved to be the best fit. This model included four main effects: session, variability, spatial working-memory and condition, and three interactions: condition*variability, session*condition 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.

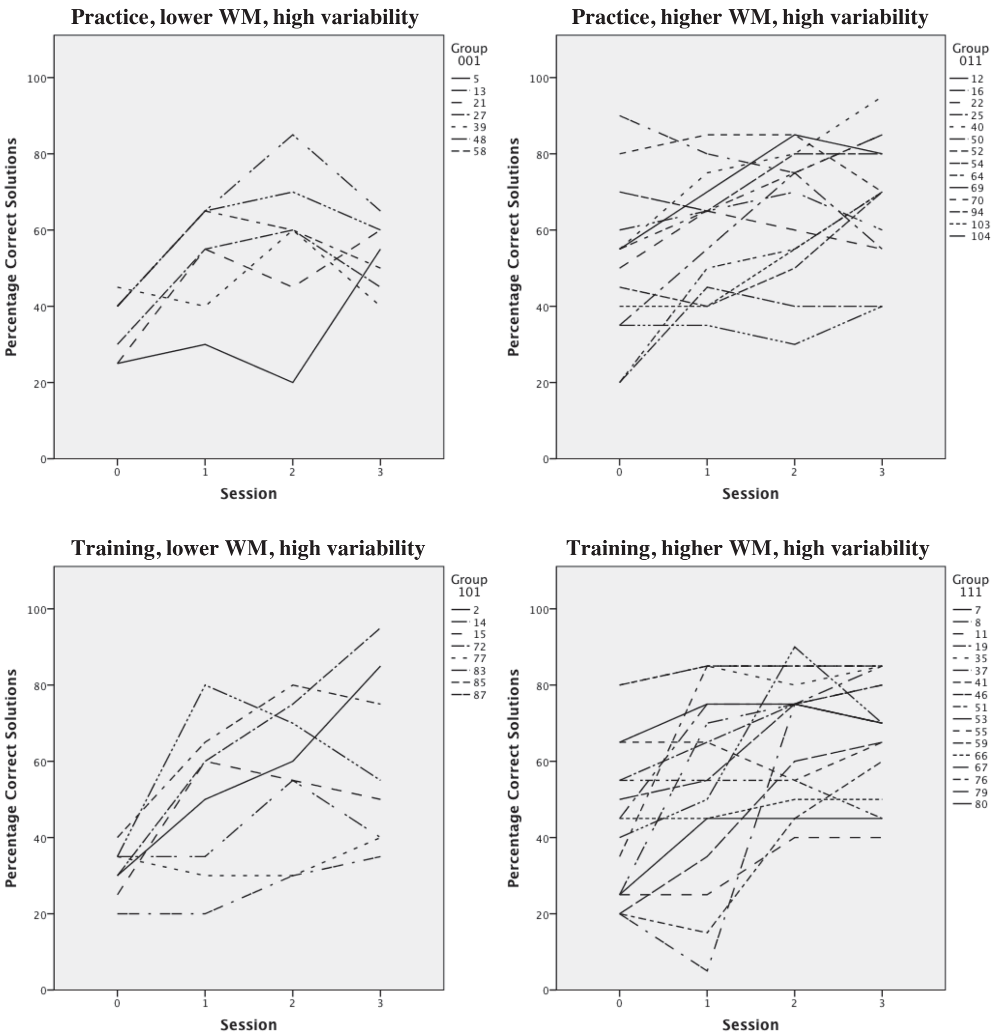
For our third outcome measure – the number of explained transformations – model 10 (see Table 4) once again provided the best fit. This time, the model included three main effects: variability, spatial working-memory, and condition, and three interactions: condition*variability, session*condition and 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.

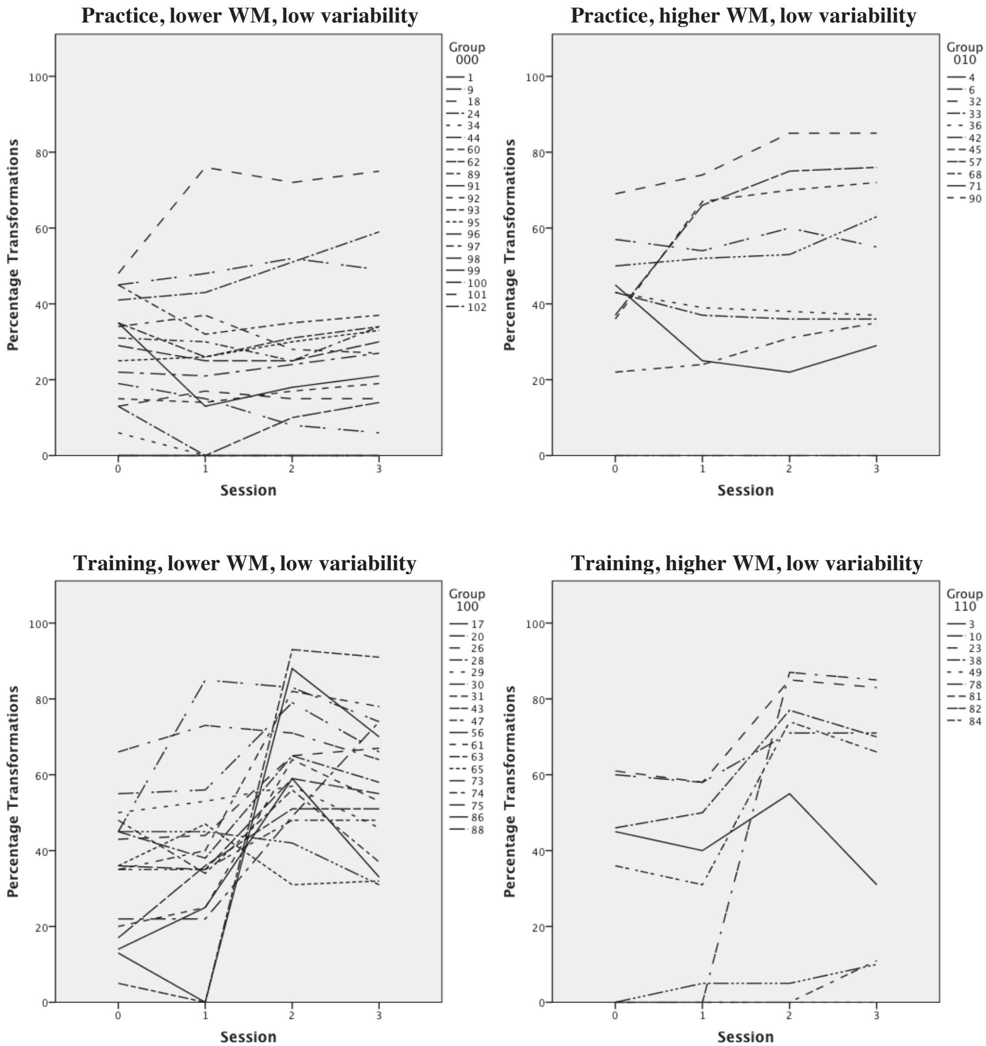


Note: WM = spatial working-memory. Group code numbers: 1st = condition: 0 = practice and 1 = training; 2nd = spatial working-memory: 0 = lower and 1 = higher; 3rd = variability: 0 = low and 1 = high.



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
Session
0
1
2
3
0
20
40
60
80
100

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.

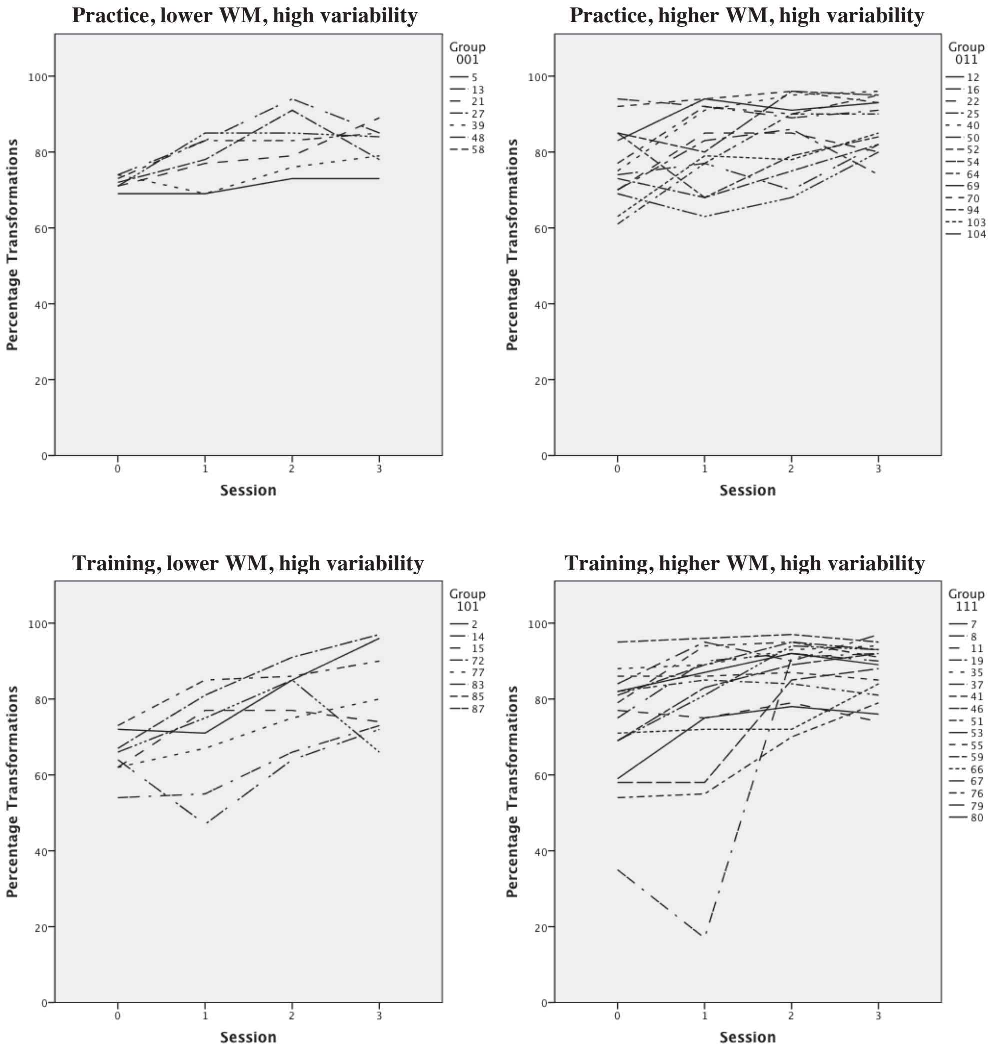
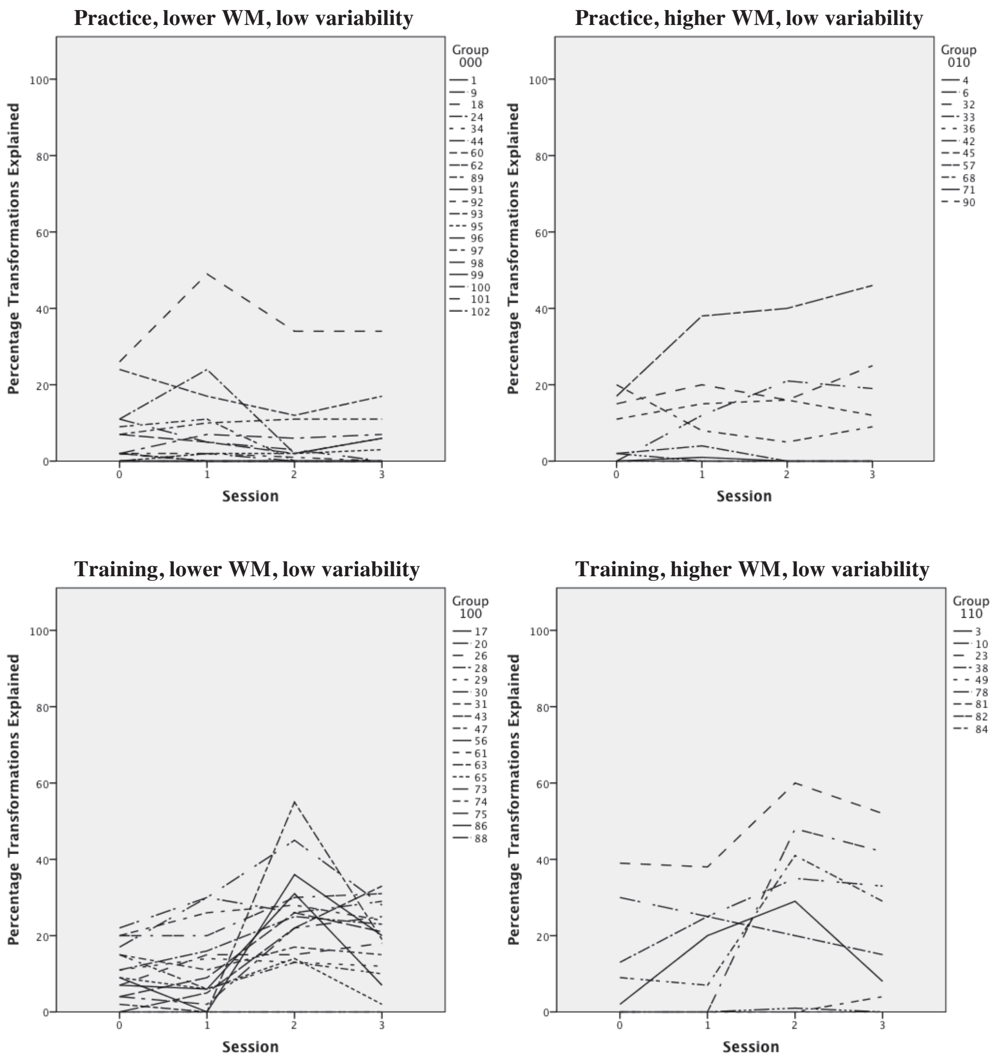
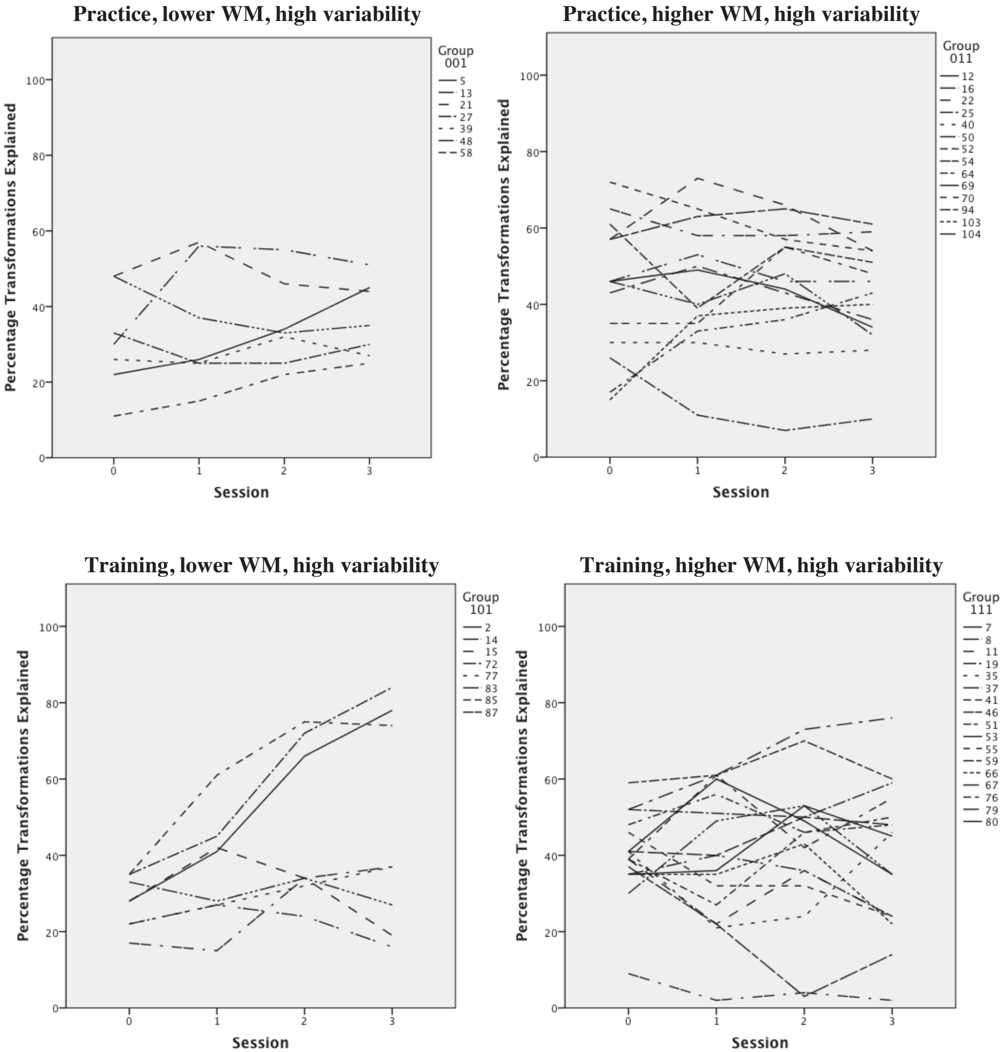

Practice, lower WM, high variability
Percentage Transformations
Session
Group 001
5
13
21
27
39
48
58
Practice, higher WM, high variability
Group 011
12
16
22
25
40
50
52
54
64
69
70
94
103
104
Training, lower WM, high variability
Group 101
2
14
15
72
77
83
85
87
Training, higher WM, high variability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

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



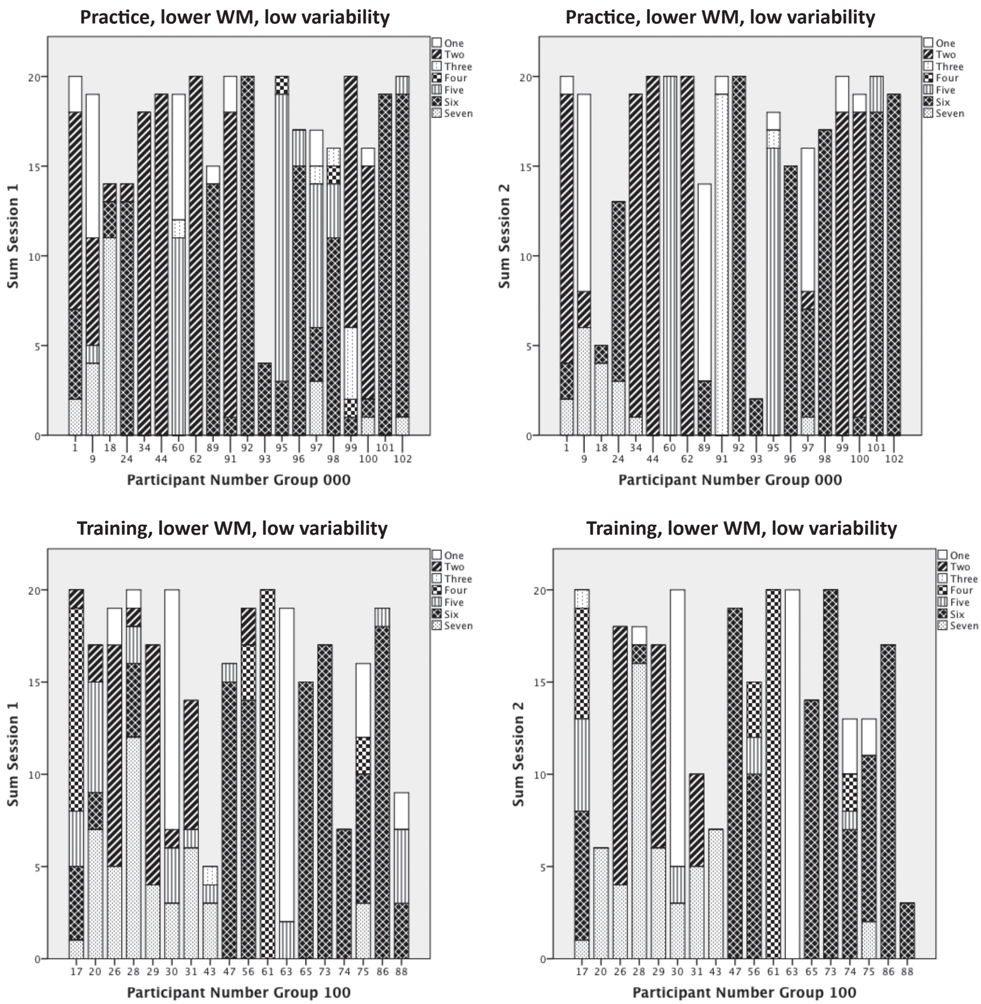
Note: WM = spatial working-memory. Group code numbers: 1st = condition: 0 = practice and 1 = training; 2nd = spatial working-memory: 0 = lower and 1 = higher; 3rd = variability: 0 = low and 1 = high.



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.

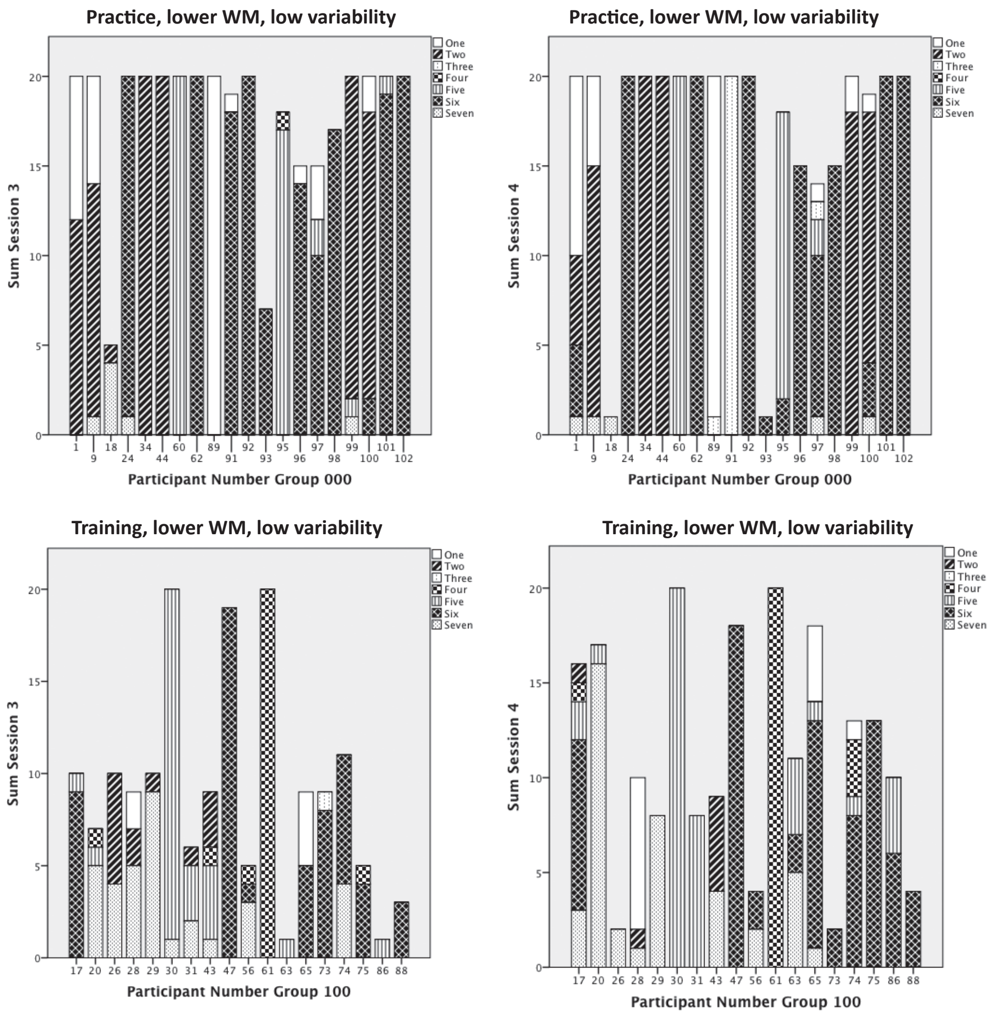
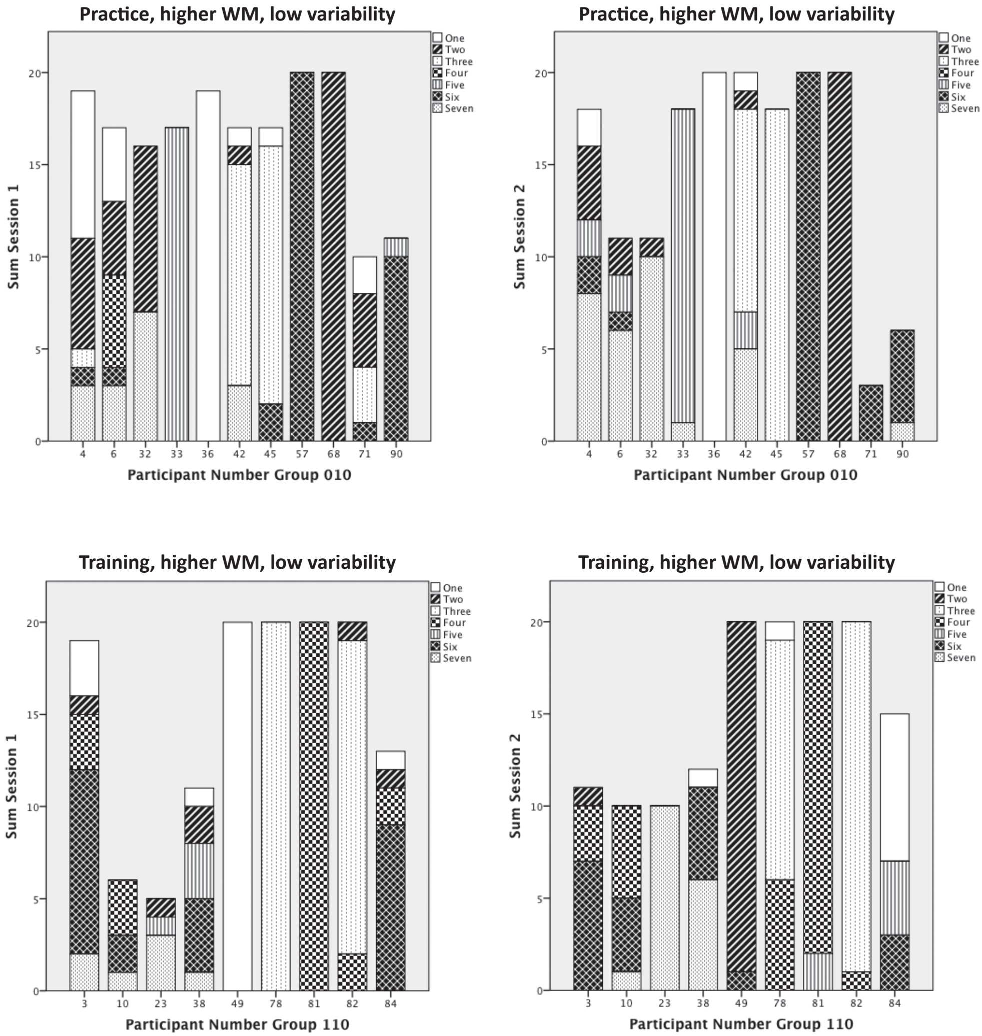
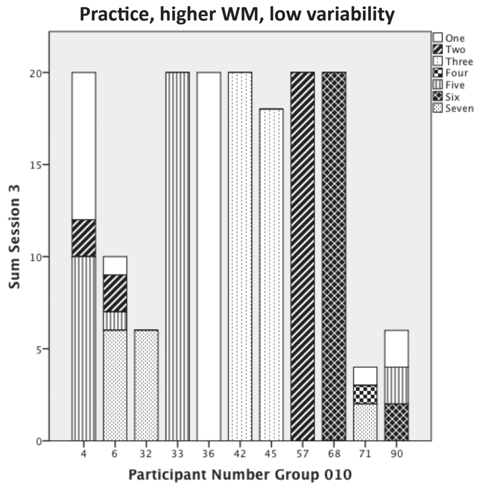
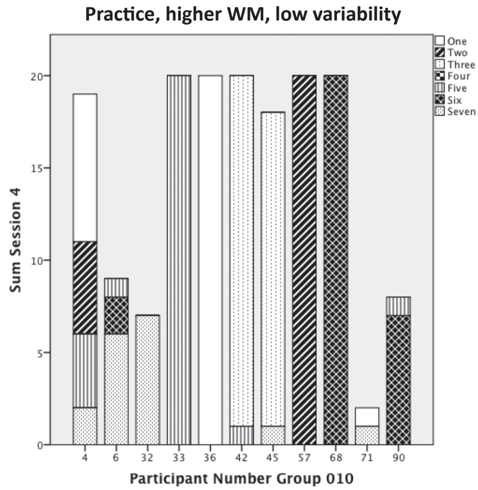

Practice, lower WM, low variability
Sum Session 3
Participant Number Group 000
Practice, lower WM, low variability
Sum Session 4
Participant Number Group 000
Training, lower WM, low variability
Sum Session 3
Participant Number Group 100
Training, lower WM, low variability
Sum Session 4
Participant Number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

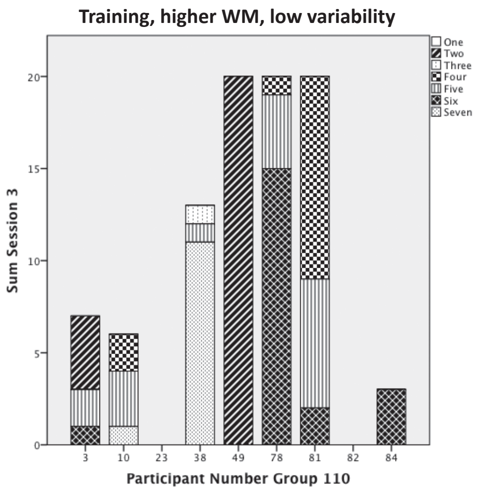
Figure 8 Explanations of solution strategies[1] (non-analogical and implicit analogical) per child and session.



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


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


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

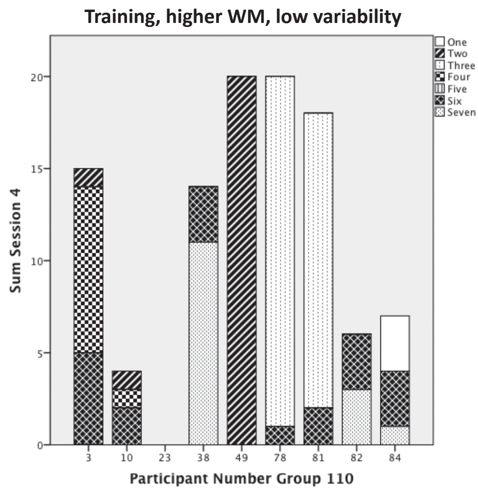
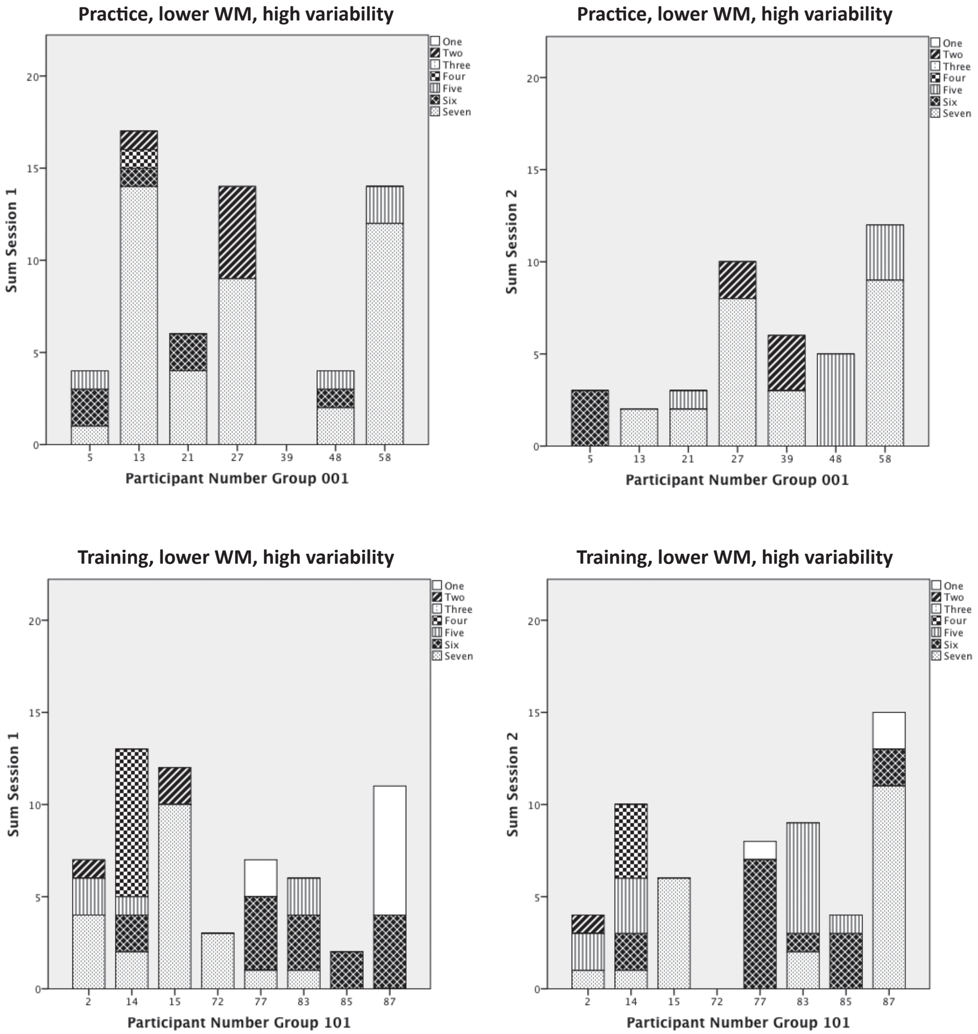

Training, higher WM, low variability
Sum Session 4
Participant Number Group 110
0
5
10
15
20
3
10
23
38
49
78
81
82
84
One
Two
Three
Four
Five
Six
Seven

Figure 9 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 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.

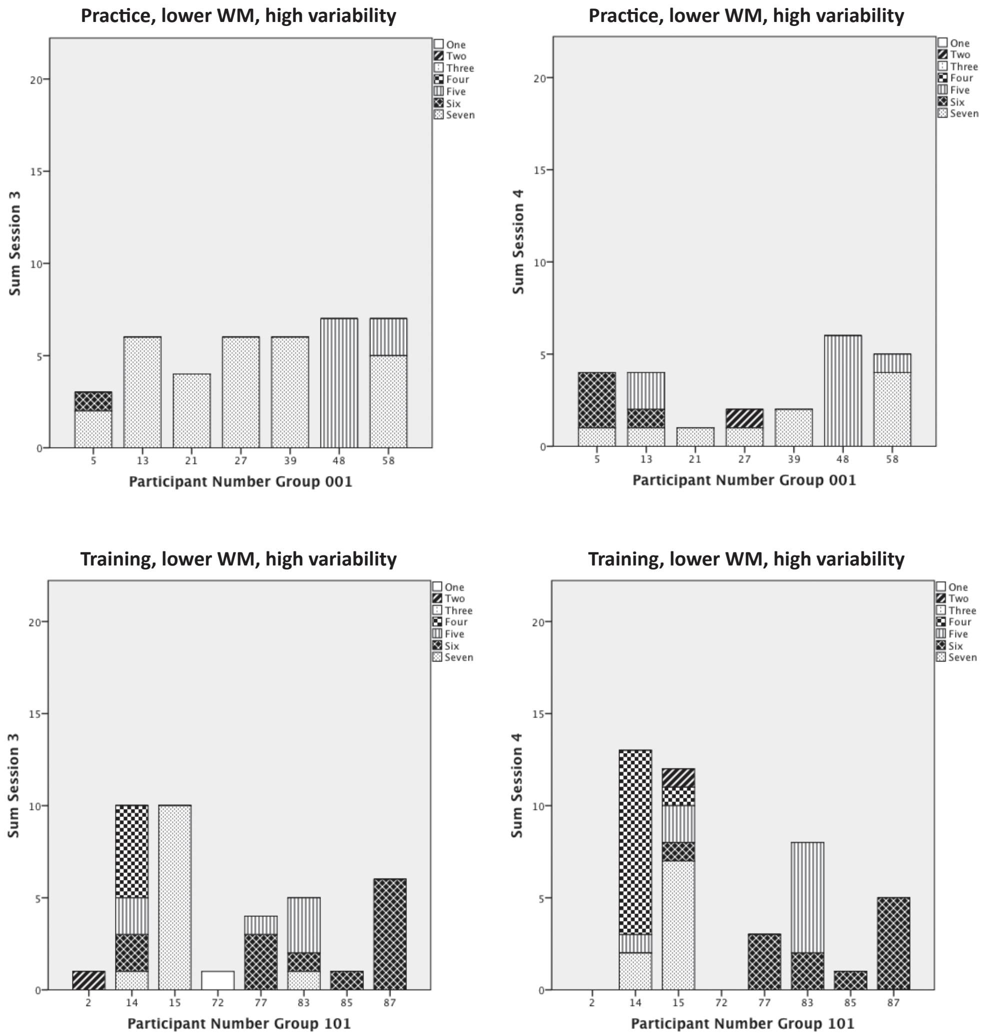
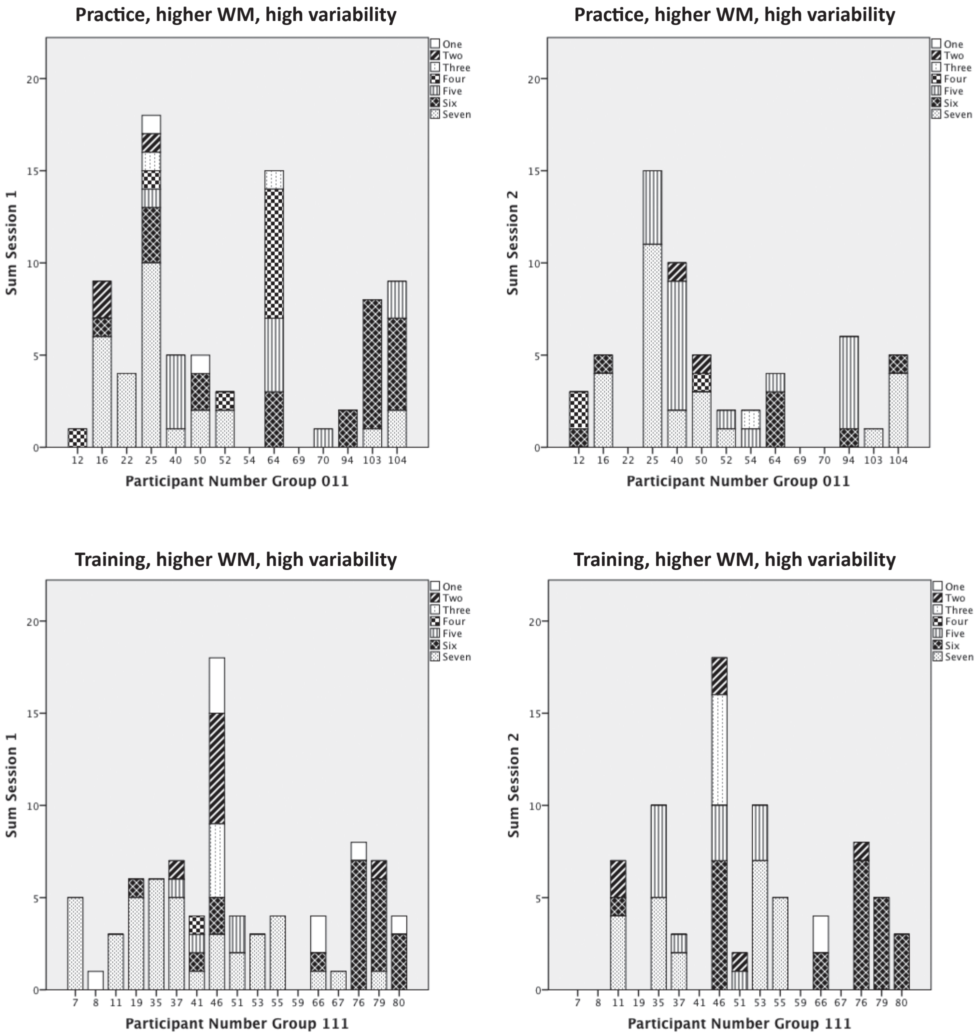
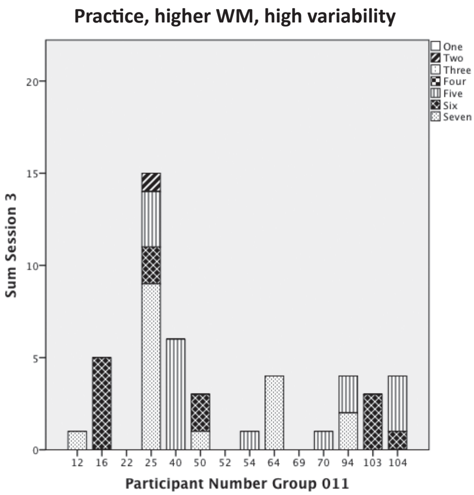
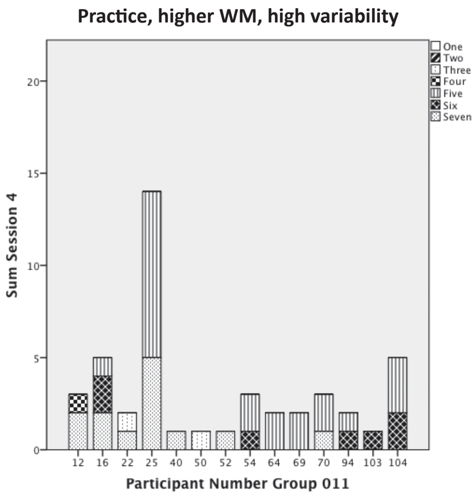

Practice, lower WM, high variability
Sum Session 3
Participant Number Group 001
Practice, lower WM, high variability
Sum Session 4
Participant Number Group 001
Training, lower WM, high variability
Sum Session 3
Participant Number Group 101
Training, lower WM, high variability
Sum Session 4
Participant Number Group 101
One
Two
Three
Four
Five
Six
Seven

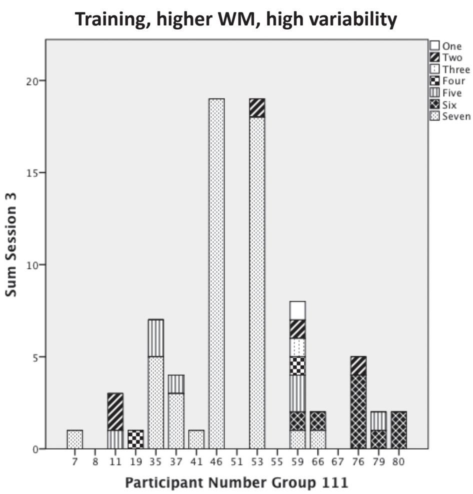
Figure 10 Explanations of solution strategies[1] (non-analogical and implicit analogical) per child and session.

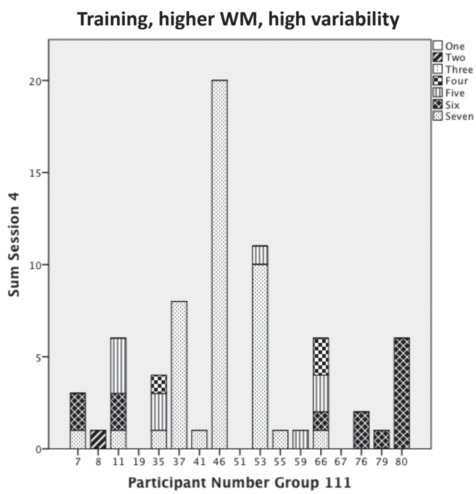


Note[1]: strategies: 1=copy; 2=part copy; 3=procedural; 4=story; 5=don't know; 6=own rule; 7=implicit analogical. The (partial) absence of a bar represents verbalizations including at least one correct transformation (see Appendix a for a more elaborate description). WM = working-memory.
This subgroup 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, higher WM, high variability
Sum Session 3
Participant Number Group 011
12 16 22 25 40 50 52 54 64 69 70 94 103 104
0 5 10 15 20
One
Two
Three
Four
Five
Six
Seven


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
0 5 10 15 20
One
Two
Three
Four
Five
Six
Seven


Training, higher 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
0 5 10 15 20
One
Two
Three
Four
Five
Six
Seven


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			
Variable names	Description	Range	
		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.