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.