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A process approach to children's understanding of scientific concepts: A longitudinal case study

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ABSTRACT

In order to optimally study changes in the complexity of understanding, microgenetic measures are needed, and a coupling of these to longer-term measures. We focus on the interaction dynamics between a 4-year old boy and a researcher while they work on tasks about air pressure in three subsequent sessions. The complexity of the utterances of the researcher (questions) and the boy (answers) was measured using a skill theory-based scale. Over the course of the three sessions, an increase in the boy's number of right answers occurred, and the frequencies of the complexity levels shifted. With regard to the interaction dynamics, the boy initiated significantly more simultaneous in- and decreases in complexity level over time, whereas the researcher initiated less. At the same time, the boy showed an increase in his mean understanding level. Therefore, on the longer term, learning may be related to taking more responsibility for generating lines of thought.

As developmental psychologists studying educational settings, we are interested in how children learn during a task, how the person–context dynamics shape this learning process, and how understanding develops over time. While studies taking measures over longer time periods (over the course of months) reveal general developmental trends of learning, they provide little insight into the short-term mechanisms of change (e.g., during a lesson). In contrast, microgenetic studies – studies of processes that unfold during a short time span – provide important insights into how actual change in learning occurs, and how the link between teaching and learning is formed (Granott & Parziale, 2002; Siegler, 2006). Given the cyclical causal relationship between the short- and long-term time span of learning, we see an additional necessity to couple these microgenetic processes to mechanisms on the long-term time scale of development. That is, one should describe and explain how short-term learning events influence long-term development and vice versa (Granott, 2002; Steenbeek & Van Geert, 2013).

This article focuses on three interactions between a 4-year old boy and a researcher while working on scientific tasks about air pressure. Using time-serial microgenetic data of the boy's reasoning, we explore fluctuations in his understanding, and examine how the child–researcher dynamics shape this learning process, as well as how these dynamics change over time during two subsequent visits. We will use tools inspired by the (dynamic systems) complexity approach (Van Geert, 2008; Van Geert & Steenbeek, 2005a), and dynamic skill theory (Fischer & Bidell, 2006). First, however, we define the concept of scientific understanding from a macro- and microdevelopmental perspective.

1. Defining scientific understanding

Multiple studies on scientific learning show that students develop various concepts about scientific phenomena during their (early) school years (Linn & Eylon, 2006; Zimmerman, 2005). These scientific concepts can be defined as ideas about phenomena in the domains of chemistry, physics, and biology (Baartman & Gravemeijer, 2011; Organization for Economic Co-operation and Development & Program for International Student Assessment, 2003). Children use these concepts in combination with inquiry skills (tool use, analogical reasoning, manipulation of variables) to reason scientifically (Zimmerman, 2005). From a macrodevelopmental perspective, children's understanding of various scientific concepts has been studied, such as gravity (Novak, 2005; Palmer, 2001; Sharp & Sharp, 2007), air pressure (Séré, 1986; She, 2002; Tytler, 1998), electricity (Chiu & Lin, 2005; Shipstone, 1984; Zacharia, 2007), chemistry (Garnett, Garnett, & Hackling, 1995; Taber, 2001), gear wheels (Dixon & Bangert, 2002; Lehrer & Schauble, 1998), and the universe (Albanese, Neves, & Vicentini, 1997; Dunlop, 2000). These studies have given an idea of global developmental trends across cohorts by focusing on specific outcomes of the learning process, such as scores on knowledge tests (e.g., before versus after an intervention), as well as the number, categories and accuracy of children's concepts. Microgenetic studies, on the other hand, have investigated the developmental trajectories of scientific concepts in detail, mostly over a short period of time, such as during a task or science lesson. In particular,

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these studies have examined the short-term path (changes in conceptual understanding), rate of change, breadth (whether acquired skills generalize to other tasks), source (what contextual factors influence learning progress), and intra-individual variability in strategies, actions, or thinking (Siegler, 2006).

Despite the progress microgenetic studies have made in unraveling the characteristics of learning and development (see for example Goldin-Meadow, Alibali, & Church, 1993; Granott, Fischer, & Parziale, 2002; Kuhn, 2002), more processes of change and mechanisms facilitating change in learning situations have yet to be identified (Flynn & Siegler, 2007). Researchers studying complex systems can offer a rich set of tools to analyze microdevelopmental patterns and link these to general developmental trends. The properties associated with complex systems, such as the soft-assembly of multiple components, and the recursive nature of development, may help to interpret and explain patterns found in microgenetic studies (Thelen & Corbetta, 2002). Of particular importance is the connection of several microgenetically coded learning interactions to provide a picture of learning over a longer term. Focusing on two dynamic properties (intra-individual variability and person–context dynamics), this paper shows how learning interactions can be microgenetically analyzed to examine how a boy's understanding is constructed during one science task, and how this relates to his learning over the course of two subsequent tasks.

2. Using dynamic skill theory to take microgenetic measures of understanding

In many microgenetic studies, researchers choose to code and analyze video-data, to prevent disrupting the unfolding process as much as possible. Skill theory (Fischer, 1980; Fischer & Bidell, 2006) includes a scale that provides a useful tool for coding such data. Skill theory focuses on the complexity and variability of children's skills, which consist of actions and thinking abilities, embodied in verbal and non-verbal behavior. Used in a microgenetical way, the scale enables researchers to extract the complexity (of e.g. utterances) from content, which makes it possible to compare understanding across multiple time points, contexts, and persons (Parziale & Fischer, 1998). Learning is defined as building collections of skills, which are hierarchically ordered in 10 levels grouped into three tiers. The first tier consists of sensorimotor skills: simple connections of perceptions to actions or utterances. The second tier consists of representational skills; these are understandings that go beyond current perception–action couplings. The third and final tier consists of abstractions, which are general nonconcrete rules that also apply to other situations (Schwartz & Fischer, 2004). Within each tier, three levels can be distinguished: single sets, mappings (a relation between two single sets), and systems (a relation between two mappings).

Although skills are hierarchically ordered, learning does not entail a linear progression through the levels. Instead, it is driven by many microdevelopmental steps forward and backward (Van Geert & Fischer, 2009). Even during a single task, people vary constantly within a bandwidth between their highest and lowest possible complexity levels, also known as the developmental range. The highest levels of this range are only reachable when the environment provides sufficient support (Fischer & Bidell, 2006; Yan & Fischer, 2002). Skill theory thus accounts not only for intra-individual variability in learning, which has been of growing interest in developmental psychology (e.g., Thelen & Smith, 1994; Van Geert & Van Dijk, 2002; Van Orden, Holden, & Turvey, 2003), but also for the dynamics between person and environment (skills emerge in specific contexts, and differ depending on the support offered), which have been emphasized by many (Fogel & Garvey, 2007; Thelen & Smith, 1994; Van Geert & Fischer, 2009). These two properties will be illustrated below.

3. Structured intra-individual variability

Intra-individual variability is crucial to understand developmental phenomena (Siegler, 1994), given that development is by definition a real-time iterative process within individuals (Van Orden et al., 2003). Information about fluctuations in people's actions or thinking can thus help to describe and understand cognitive change (Siegler, 2007). From a dynamic point of view, variability is seen as a system-specific property (Steenbeek, Jansen, & Van Geert, 2012; Van Geert & Steenbeek, 2005a), meaning that the complexity of children's understanding fluctuates, even within short periods of time. Researchers studying microdevelopment found that people particularly show an increase in variability (in e.g. actions or strategies) before transitioning to a more advanced strategy (Bassano & Van Geert, 2007; Van Dijk & Van Geert, 2007), or a higher level of understanding during a task (Jansen & Van Der Maas, 2001; Yan & Fischer, 2002). Such an increase in variability is needed to explore new strategies, and ultimately, to anchor a more advanced strategy for a longer period of time (Siegler, 1996, 2007; Shrager & Siegler, 1998; cf. Simonton, 2011). The structure of intra-individual variability can be analyzed not only statistically (see Kello et al., 2010; Van Orden et al., 2003), but also functionally by describing which levels are observed and how these relate to the ongoing interaction with the context. That is, one can investigate how fluctuations in the complexity of children's understanding relate to complexity fluctuations of the interaction partner, or in other words, focus on the child–context dynamics during a learning process.

4. Child–context dynamics

Most studies do not specifically address the continuous intertwining of person and context (Richardson, Marsh, & Schmidt, 2010), but instead view the environment as “system input” (p. 5), that is, an independent variable that influences the person, or interacts with certain characteristics of the person. Viewed dynamically, however, behavior is a “dynamic, self-organized consequence of the physical laws and informational constraints that are mutually structured across mind, body, and environment” (Richardson et al., 2010, p.8). The child's understanding of a concept, is the child's continuously changing cognitive state, as he or she reacts to the current dynamic interaction (Van Geert, 2011). Since understanding is a self-organizing process assembled of three interactive components (boy, researcher, and task), certain patterns in the interplay of the complexity of questions and answers might emerge. For example, fluctuations (i.e., intra-individual variability) in understanding may be influenced by not only the ongoing interaction with the context, but also the other way around (Van Der Steen, Steenbeek, & Van Geert, 2012). That is, increasing complexity of the researcher's questions about the task may be related to increasing complexity of the boy's answers. In addition, one would also expect the researcher to adjust the complexity of her questions to the complexity of the boy's previous answers (see the literature on scaffolding, e.g., Van Geert & Steenbeek, 2005b). Over time this process might change. When the boy and researcher are more adapted to one another, and when the boy has a (partial) understanding of the procedure and concepts asked during a task, he might take more initiative in directing the conversation. As a metaphor, one could picture a dance. The researcher can only lead if the boy follows, and vice versa. A switch in this lead might indicate that the boy has at least a partial understanding of the task, and that he feels confident to demonstrate this. It is, however, important to keep in mind that there is always a mutual coupling between dance partners. That is, there is no simple notion of unidirectional causality, since the coordinated movements emerge as a result of joint activity.

5. A case study — research questions and hypotheses

This case study is focused on a typically developing 4-year old boy, who worked together with a researcher on a task about air pressure