Peer Interaction and Scientific Reasoning Processes in Preschoolers
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Chapter 6

General Discussion
1. Research Motivation and Context

Understanding the processes of reasoning and interaction during learning activities is essential to generate rich learning environments and to promote children's reasoning skills. In the last three decades, empirical research has shown that children not only are able to reason and learn in complex, structured and abstract ways from early childhood onwards (Gopnik, 2012), but also that they learn and develop through the interaction with others (Doise, Mugny & Perret-Clermont, 1976, Rogoff, 1990; Valsiner, 1994; Valsiner, Branco & Dantas, 1997). Moreover, developmental theories have described which cognitive skills children are able to achieve at certain ages. However, a challenge that remains is to understand how these processes of reasoning and interaction take place and evolve over time. The focus of this dissertation is on exploring how scientific reasoning (i.e. scientific reasoning skills, skill levels and transfer) and dyadic interaction of 5-year-olds emerge and change in a sequence of problem-solving tasks. The empirical studies are based on the children's behaviors that occur in real-time, and are focused on analyzing the history of changes in the trajectories in the short- and long-term time scale. The design consisted of six waves of data collection – each one with a duration of approximately 25 minutes-, in the course of one school year. The age of five years was selected because it corresponds to a transitional period in the development of the reasoning skills. Around 5 years of age, children's understanding becomes more complex because they change their focus from identifying a single characteristic of the objects (i.e. single representations) to establishing relations between several attributes (i.e. representational mapping) (see Fischer, 1980, 2008).

Based on the complex dynamic systems approach, we follow the children's reasoning and interaction by using repeated measures. The assumptions of this approach are that human behavior is variable and self-organized (van Dijk & van Geert, 2015), and that for studying processes it is necessarily to consider the variable of time (van Geert, 2011). The methodological core of the studies presented in this dissertation consists of an examination of the intra-individual variability of case studies. This approach—known as idiographic method (Molenaar & Valsiner, 2005)—is centered on individual change. In contrast to the standard approach of group-based analyses (between-subject variation), the idiographic method (focusing on within-subject variation) provides valuable information about the underlying psychological processes, its patterns and changes over time (Molenaar, 2003; Velicer, 2010).

Based on complex dynamic systems principles, such as self-organization, dependence on time, recurrence, multi-causality and nested time-scales, we described
children's behaviors as the result of soft-assembly (Kloos & van Order, 2009), in other words, as emerging in the 'here and now', in interaction with specific task content. The empirical studies of this dissertation explored several aspects. On the topic of reasoning, we focused on (1) the use of three scientific reasoning skills (descriptions, predictions and explanations), (2) the complexity levels of reasoning expressed in actions (implicit knowledge) and verbalizations (explicit knowledge), and (3) transfer of reasoning across a sequence of tasks. For the topic of interaction, the focus was on (4) the individual types of children’s interactions during the problem-solving activities (no work, passive, copy, parallel and collaborative work), but also (5) the dyadic interaction types of distributed dyadic interaction (DDI) and unequal dyadic interaction (UDI), indicating the engagement of the two children with their partner and the task. In addition, we explored how the interaction types (at the individual or dyadic level) were related with the use of scientific reasoning skills. Our aim was to identify the concrete and real patterns of reasoning and interaction of the preschoolers in the context of problem-solving and spontaneous experimentation.

We applied a variety of methods to capture the richness of the data. The empirical data are based on time series of coded behaviors that stem from video-recordings of children working on problem solving tasks. These time-series were explored with different techniques, such as hierarchical agglomerative cluster analysis (HAC, Hastie, Tibshirani & Friedman, 2009), transition matrices (Ivanouw, 2007), State Space Grids (SSG, Hollenstein, 2013), Hamming distances (see Lichtwarck-Aschoff, Kunnen, & van Geert, 2009) and Cross Recurrence Quantification Analysis (CRQA, Marwan & Webber Jr., 2015). What these techniques have in common is that they reveal the characteristics and patterns of variability by tracing the temporal changes in the time-series of the observed behaviors.

2. Summary of Findings

In the first two studies (chapters 2 and 3), we analyzed the relation between interaction and scientific reasoning. In Chapter 2, we presented a case-study of two dyads working in a single session with a balance-scale task. In this study, we carried out a micro-developmental analysis of the changes that take place from moment to moment. Here, the focus was on identifying the co-occurrence of five types of interactions (i.e. no work, passive, copy, parallel and collaborative work) with the use of the three types of scientific reasoning skills (i.e. descriptions, predictions and explanations) in children's verbalizations. The results show clear individual differences in scientific reasoning. In one of the cases, one of the children led the interaction with the use of the most complex skills (i.e. explanations and predictions),
whereas in the other case, both children used all the reasoning skills. In addition, the use of reasoning skill did not remain stable along the tasks, but fluctuated over time. With regard to the verbal interactions, parallel and passive work were predominant, whereas collaborative interactions were barely present.

In Chapter 3, we wanted to explore how the dyadic interaction evolves over repeated problem-solving sessions and how it relates to reasoning. The individual categories of interaction – as described in chapter 2 – were used to form a dyadic model consisting of two dimensions: Distributed Dyadic Interaction (both children work on the task) and Unequal Dyadic Interaction (only one of the children works on the task). The results show that the most complex reasoning skills (i.e. explanations and predictions) were present during two main patterns of dyadic interaction (as in Chapter 2): parallel-parallel work (corresponding to distributed dyadic interaction) and parallel-passive work (corresponding to the unequal dyadic interaction). These two patterns seemed to be rather stable across all sessions, even with the increasing difficulty of the tasks. Whereas earlier studies suggest that collaboration is an ideal learning scenario, these findings show that collaboration is not a central characteristic of spontaneous dyadic interaction as a way to solve problems (Bahrami, Olsen, Latham, Roepstorff, Rees, & Frith, 2010; Koriat, 2012). It should also be noted that we used a very lenient definition of ‘collaboration’ including all types of verbal interactions and responses, which is not is not very different from the way collaboration happens in the classrooms. Therefore, the findings indicate the presence of a spontaneous ‘independent’ style of problems solving and the lack of interest in sharing views and building knowledge collaboratively (see also Mercer, Dawes, Wegerif & Sams, 2004).

In Chapter 4, we examined the dyadic interaction from a different angle. Here, the two main dyadic dimensions of Distributed Dyadic Interaction (DDI) and Unequal Dyadic Interaction (UDI) – as described in Chapter 3 – were used to characterize the interpersonal coordination of the dyads in a series of problem-solving tasks (air pressure and inclined plane tasks). By considering the dyad as a system, our aim was to characterize the underlying dynamics of their interaction in terms of attractor states (see Hollenstein, 2013). Across the repeated sessions of the tasks, the temporal analysis (Cross Recurrence Quantification Analysis, CRQA) showed the predominance of DDI over UDI. However, the dynamics of these two attractors were similar in the sense that in both, the dyadic coupling became more flexible and more complex over time.
In Chapter 5, different aspects of the children’s reasoning were brought together to examine the long-term changes in a series of problem-solving tasks (air pressure and inclined plane tasks). Specifically, we examined the complexity of the optimal performance of the children’s actions (implicit knowledge) and verbalizations (explicit knowledge) in the context of spontaneous experimentation, and also the transfer of scientific reasoning. In the first part of our examination, we found that on average, the overall skill levels of reasoning of the dyads were higher for actions than for verbalizations. This difference was stable for the entire measurement period, suggesting that children show a better understanding when they solve the tasks rather than explaining them. In actions, children were able to establish partial and total relations with the tasks’ elements, while in verbalizations they were mainly focused on naming the attributes of the materials and to establish some basic relations between the task’s elements. This finding suggests that in this age range, the implicit knowledge (actions) is and remains more advanced than explicit knowledge (verbalizations). However, it may also suggest differences in the demands of performing implicit and explicit knowledge, and the relation of these two types of knowledge with the affordances of the tasks. With regard to the individual trajectories of reasoning, we found clear differences in the individual performance over time that cannot be interpreted as straightforward random variations on a common pattern. This indicates that the findings of the group analyses cannot be generalized to the individuals and vice versa. The second part of our examination was about the trajectories of transfer in which we analyzed the changes in the elements used by the children to solve the sequence of tasks. On average, the children’s performance seems to show a gain of knowledge in subsequent tasks. However, the intra-individual trajectories of transfer turned out to be more variable. There was no global increase or decrease across time, but there constant fluctuations, indicating that variability is a characteristic of how transfer takes place.

3. Integrative Findings

The different findings of our studies leave us with various ideas about how spontaneous learning and social interaction take place in real-time during problem-solving situations. In our studies, children discovered the solutions by exploring functional relations between the task’s elements (in actions and verbalizations) without receiving instructions to solve the tasks. Although children’s explanations do not include all complex actions they performed on the task, they were able to mention relevant attributes and causal relations about the task. In contrast to a traditional analysis focused on success and fail, more information about the children’s behaviors
can be obtained by actually observing the history of changes in real-time and in the self-organization of their performance towards a goal (e.g. Meindertsma, van Dijk, Steenbeek & van Geert, 2014; van der Steen, Steenbeek, & van Geert, 2012).

The dyadic interaction reveals the spontaneous relation between the children and the task. Children seem to prefer an independent style by working simultaneously on the tasks or taking turns over a collaborative style. This finding suggests that for the 5-year olds the strategy of joining efforts is not as relevant as finding their own way out of the challenging situations. Furthermore, looking at the changes of the interactions, we have seen that children do not take a stable role in the interaction across the learning situations (e.g. collaborating, leading or remaining passive) but that they alternate between different types of interaction and levels of engagement with their partner and the task. Although independent work (i.e. parallel work) occurs most frequently, it is not the only type of interaction that was used during the process of scientific reasoning. This finding suggests that the relation of particular types of interaction and complexity levels of scientific reasoning is not unidirectional but multidirectional, influencing each other.

One conclusion of this dissertation is the idiosyncrasy of the children's behaviors and the way they develop and change over time. Though in some cases there were clear and robust trends in the development as a group, the individuals took different paths. At the individual and dyadic level, we also found considerable variability at different time-scales. These results emphasize the nonlinearity of the observed processes (see also Meindertsma, van Dijk, Steenbeek & van Geert, 2014; Steenbeek & van Geert, 2008). The observed behaviors turned out to vary not only across different tasks and sessions, but also within the same task. This is consistent with findings from other domains of learning and development, in which variability is an essential characteristic of development (Alibali & Sidney, 2015; van Dijk & van Geert, 2015). With regard to the variability in the children's interactions, we have found particular regularities or recurrent behaviors. For instance, we showed that the dyadic patterns of interaction (i.e. distributed and unequal dyadic interactions) worked as attractor states of the dyadic system, and that they become somewhat more flexible and complex over time. Therefore, the observed variability is not a 'measurement error', but represents meaningful structure of the behaviors. This fits with the idea from the complex dynamic systems approach, which explains variability as the result of the soft-assembly of behaviors of each attempt to solve the task (see Kloos & van Orden, 2009). In our studies, the behaviors of interaction and reasoning emerge from the soft-assembly of the children's skills (social and cognitive), the features of the problem-solving context and the history of these elements. According to Spencer,
Clearfield, Corbetta, Ulrich, Buchanan and Schöner (2006), the soft-assembly process allows the human behavior to be flexible and adapted to the demands of the context. The observed variations in the interaction and reasoning of the preschoolers support the non-ergodicity condition of psychological processes (Molenaar, 2010). This condition entails that psychological processes are not homogeneous or static (i.e. ergodic principles), but variable over time. Our findings add support to the idea that the process of interaction and reasoning on 5-year-olds are ruled by dynamic principles (i.e. non-linearity, recurrence, formation of attractors, multi-causality, and nested time-scales).

Our studies have various implications for the educational context. The first one is that collaborative work as a strategy of learning needs to be guided in preschool ages in order to occur. As has been suggested by Teasley (1997), it seems that at this age children require explicit instructional support to discover the benefits of working in collaboration as a strategy to gain knowledge (Fawcett & Garton, 2005, Garton & Pratt, 2001; Slavin, 1996). The second implication is that independent work while working in the presence of others is an important source for preschool children to spontaneously solve situations. Therefore, educational practices can also provide space for children to display their own efforts in learning activities. A third implication is that both actions and verbalizations should be seen as indicators of children's reasoning. We have demonstrated that problem-solving actions are often more complex than what is verbally expressed. This means that teachers have to consider both verbal and nonverbal types of reasoning when assessing children's understanding. In addition, teachers must learn to interpret actions as expressions of deep insights of the children's reasoning. Finally, teachers should also consider the individual differences between children by acknowledging that not all children follow the same path of learning that the group.

4. Limitations

Aside from the specific limitations that have been mentioned in the separate chapters, there are some general limitations of this dissertation as a whole. The first limitation is related to the implications for educational settings. In our studies, we have observed the behavior of the dyads working only in the presence of the researcher. We are aware that this context of interaction may not be fully representative of the natural conditions in a regular classroom, in which a teacher and a group of children are constantly interacting. In addition, the protocol used in these studies is not the same as the scaffolding process of the teacher with their students. Although the situations created for these studies may be less complex in terms of the
interactions with the adult, we are convinced that the processes described in our studies can also be found in naturalistic conditions (e.g. a teacher working on a science lesson). We are aware that when studying similar processes in a larger teaching group, more variations will probably be found, because changes in the interacting elements of the system can lead to different emerging behaviors (Alibali & Sidney, 2015). A second limitation related to the use of the current protocol is that children did not have the opportunity to elaborate more on their explanations. Since the elaboration of explanations is beneficial for learning (Legare & Lombrozo, 2014) and considering the fact that young children have difficulties evaluating their own explanations (see Legare, Schepp & Gelman, 2014), the use of more questions can be useful at this respect. A third general limitation is that it is difficult to know exactly how much the children of the dyad influence each other even when they work independently. For instance, we found that children mainly work independently (i.e. parallel work) to solve the tasks. However, we do not have information about how much of the individual performance is based on the individual exploration or on the observation of the other member of the dyad. We also do not know how much knowledge is gained from the content of the tasks (see an illustration of these aspects in Yang, Sidman, & Bushnell, 2010). For now, we can argue that the understanding of the dyads as a system without trying to isolate their specific parts, due to the dyad is the result of the interaction between the children and the task, even when they are “doing things individually together”.

A final limitation of the study is the bilingual context in which the studies took place. One possible concern that arises is whether the children's verbalizations were restricted by their knowledge of the second language (i.e. English) that was used in the protocols. However, we verified with their teachers that all the children were fluent in the second language before starting the data collection. In addition, it is important to mention that the second language was used in most of the children's families because the parents had different nationalities. Although we cannot be sure that the results would be identical for monolingual children, we are convinced that the performance of the participants was not particularly hindered by their bilingualism due to their strength and fluency in English.

5. Concluding Remarks

Altogether, the findings in this dissertation indicate that both interaction and reasoning skills of preschoolers are characterized by idiosyncratic patterns. This is not surprising, considering the non-linear nature of developmental processes
(Valsiner, 2006; van Dijk & van Geert, 2015). We hope that our findings can provide insights in the design of learning contexts and assessments that involve different ways in which the children can acquire particular levels of knowledge. Recognizing the several dimensions that characterize peer interaction and reasoning during problem-solving activities, can lead to better instructional support in the classroom to foster the learning opportunities of the children, individually and in the interaction with others.
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