A developmental psychology perspective on preschool science learning: Children's exploratory play, naïve theories, and causal learning

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CHAPTER 1

General introduction

PRESCHOOL SCIENCE EDUCATION & CURIOUS MINDS

Young children's readiness for science becomes clear when looking at their curiosity and potential. They have an intrinsic motivation to explore the world around them, which has also been described as an 'inborn sense of wonder' (Carson, 1984; Eshach & Fried, 2005). In addition, they have strong cognitive competencies in a number of areas and can, to a certain extent, reason scientifically (Eshach & Fried, 2005; Gelman & Brenneman, 2004). Results of numerous studies contradict the Piagetian idea that young children are incapable of abstract logical thought (e.g. Gopnik, Sobel, Schulz & Glymour, 2001; Siegel, McCabe, Brand & Matthews, 1978; Sobel, Tenenbaum & Gopnik, 2004). For example, Gopnik et al. (2001) have shown that preschoolers are capable of making causal inferences on the basis of patterns of variation and covariation. With respect to future achievement, is often argued that engaging in science activities at a young age could lead to the development of positive attitudes towards science, and improved self-confidence and performance in science (Arnold, Fisher, Doctoroff & Dobbs, 2002; Clements & Sarama, 2007; Eshach & Fried, 2005; French, 2004; Neuman, 1971).

In line with these observations, the US National Academy of Science (Duschl, Schweingruber & Shouse, 2007) and National Science Board (2009) have stressed the importance of preschool science education. The last decade both formal and informal science activities for preschoolers have been developed in the US. In the field of formal learning, preschool science programs, such as 'Preschool Pathways to Science' (Gelman, Brenneman, MacDonald & Roman, 2010), 'ScienceStart!' (French, 2004), and 'Head Start on Science' (Van Egeren, 2007), were developed.[1] In the field of informal learning, preschool areas have been set up in science museums, such as the Preschool Place at the New York Hall of Science (Stevenson, 2010). In both these formal and informal settings the child is seen as an active learner who constructs her own learning experiences and hands-on activities comprise the main part of the activities (French, 2004; Gelman & Brenneman, 2004; Neuman, 1971; Ramsey & Fowler, 2004). Adult guidance of the activities is considered necessary, and a main task of the adult is to structure children's exploratory process by the teaching of process skills, such as predicting, observing, and comparing (Eshach & Fried, 2005; French, 2004; Gelman & Brenneman, 2004; Greenes, Ginsburg & Balfanz, 2004; Ginsburg & Golbeck, 2004; Neuman, 1971).

In Europe, the goal of developing a knowledge-based economy (Lisbon European Council, 2000) has renewed the interest in science education at primary and secondary levels (e.g. Rocard et al., 2007). In 2001, the Dutch government launched the 'Broadening Technical Education in Primary Education' program (VTB, www.vtbprogramma.nl). But in spite of these developments, until some years ago few science activities for preschoolers had been developed in The Netherlands. In the field of formal learning, programs aimed at supporting cognitive and social-emotional development, such as Kaleidoscoop and Piramide (e.g. Veen, Roeleveld, Leseman, 2000), had been implemented in preschools, but these programs did not focus specifically on science.[2] In the field of informal learning, science museums, such as science center NEMO (Amsterdam) and Naturalis (Leiden), had gained expertise in developing exhibitions for children, but had not developed a specific approach for creating exhibitions or activities for the preschool age group. These observations motivated Jan de Lange, Johan van Benthem, and Robert Dijkgraaf in 2006 to initiate Curious Minds (TalentenKracht, www.talentenkracht.nl), a program as part of VTB focused on the preschool age group. Since its start, Curious Minds has been a program on the intersection of research and practice. Currently, the program supports seven research groups, based at different Dutch and Belgian universities. These groups investigate young children's skills and knowledge in the science, technology, engineering and mathematics (STEM) disciplines, and study ways in which these abilities can be advanced in an optimal manner. In addition, the research groups collaborate with different parties in the field of science education to apply their research outcomes in practice. The studies in this thesis were performed within the framework of Curious Minds at the UvA research group, which is based at the section Developmental Psychology of the University of Amsterdam.[3]

RESEARCH FRAMEWORK

In line with the goal of Curious Minds to bridge research and practice, for this thesis three kinds of research-related activities were performed. First, scientific studies on young children's science learning were executed in controlled lab settings. Second, scientific studies on young children's science learning were executed in natural settings, such as daycare centers and science museums. In the science museum context, such studies are often referred to as visitor studies, and are related to work evaluating exhibits and exhibitions. However, in contrast to evaluation studies, the studies in this thesis were not solely motivated by the practice of science education, but also by the current state of research. For example, a study could be initiated by a question that an exhibition developer encountered in her interactions with children, but at the same time contribute to advancing methodologies in the field of developmental psychology. The third type of activity was the application of research outcomes in the practice of science education. To this end, the UvA research group has established a long-term collaboration with science center NEMO. The fourth paragraph in this General introduction, "Collaboration UvA and NEMO: Young explorers in NEMO", gives a brief description of the collaboration, and describes some of the resulting educational products.

This thesis investigates young children's science learning in controlled and natural settings from a developmental psychological point of view: we study the relation of specific skills and knowledge with age. In doing this, we bring together research from the fields of science education, visitor studies, and cognitive developmental psychology. A constructivist perspective is adopted (e.g. Inhelder & Piaget, 1964, Gopnik & Meltzoff, 1997; Wellman & Gelman 1992), implying that the child is taken as unit of analysis, and that learning is considered to be happening within the child's mind (Callanan & Valle, 2008). Although we consider Piaget's theory to underestimate young children's abilities, we do take his description of the "active, self-directed nature of children's cognition" (Gelman, 2009, p. 116) as a point of departure for our studies. In taking this perspective, we agree with Gelman (2009) that children not only learn from their own exploration, but that their interactions with others shape an important part of their learning experiences. Work on primary school-aged children's science learning demonstrated that self-directed discovery learning can be ineffective (e.g. Dunbar & Klahr, 1989; Schauble, 1990), and even inferior to direct instruction (Klahr & Nigam, 2004). Even though these results cannot be translated directly to the preschool age group (see Chapter 7), the importance of adult guidance in preschoolers' science learning is evident. Therefore, this thesis also examines the effects of a teacher-led sciencing program, and different adult coaching styles on young children's science learning.

This thesis has a focus on measurement, or quantification of children's knowledge and behavior. For example, this focus is reflected by the use and development of nonverbal measures for assessing children's skills and knowledge in the field of science. In many studies children's reasoning on science subjects is assessed verbally, often by interviewing (e.g. Bernstein & Cowan, 1975; Havu-Nuutinen, 2005; Tuckey, 1992; Vosniadou & Brewer, 1992). However, as young children's verbal capacities are still developing, their verbal utterances cannot be considered an accurate reflection of their level of reasoning; that is, measures relying on verbal utterances could be confounded by children's language skills. Therefore, the use of nonverbal measures yields more information about young children's capacities than the use of verbal measures (e.g. Brainerd & Hooper, 1975). The focus on measurement is also reflected by the individual differences approach that is applied in this thesis. In many studies development of science skills and knowledge is described based on average behavior of children within age groups (e.g. Flobbe, Verbrugge, Hendriks & Krämer, 2008; Sobel & Kirkham, 2006; Sobel et al., 2004). However, as preschoolers have received little formal science education, sizable differences in skills and knowledge exist within age groups. Instead of averaging over age groups, this thesis describes the development of children's skills and knowledge by taking into account individual differences; that is, by distinguishing different types of skills and knowledge and relating these to children's age. To this end, a combination of Siegler's (1981) Rule Assessment Methodology and a latent variable technique (e.g. McCutcheon, 1987; Rindskopf, 1987) were applied (Jansen & Van der Maas 1997, 2001, 2002; Raijmakers, Jansen & Van der Maas, 2004).

PRESCHOOLERS' EXPLORATORY PLAY, NAÏVE THEORIES & CAUSAL LEARNING

First and foremost, the studies in this thesis investigate young children's exploratory play.[4] Exploration is considered to be at the core of young children's science learning: preschool science programs emphasize the learning of skills that comprise exploration (e.g. French, 2004; Gelman & Brenneman, 2004), and science museums see meaningful, "minds-on" interactive behavior as indispensable to visitors' experience (Allen, 2002, 2004). Children's exploratory play is often referred to as their reasoning-in-action (Gifford, 2004; Inhelder & Piaget, 1964; Singer, 2002). To investigate preschoolers' exploratory play in natural settings, we developed the Exploratory Behavior Scale (EBS).[5] This scale fills a gap in existing measures for visitor behavior in museum settings. Compared to frequently used global measures of behavior (e.g. Boisvert & Slez, 1994, 1995; McManus, 1987) the EBS adds information about the quality of the hands-on behavior. Compared to more detailed measures of behavior (e.g. Crowley et al., 2001; Meisner et al., 2007), the EBS has the advantage of being domain-general, and applicable in different settings.

Children's exploration is affected by domain-specific knowledge (e.g. Bonawitz, Van Schijndel, Friel & Schulz, 2012; Legare, 2012), but also yields domain-specific knowledge (e.g. Gweon & Schulz, 2008; Schulz, Gopnik & Glymour, 2007). This thesis examines these processes in young children. First, we study children's naïve theories in several areas of science: in the area of biology we study theories on prenatal development, and in the area of physics we study theories on shadow size.[6] It is investigated whether children's knowledge in these ecologically valid domains is coherent, theory like, or fragmented (see DiSessa, Gillespie & Esterly, 2004 for a review). Second, we investigate how children's domain-specific knowledge affects their exploration by examining the effect of evidence conflicting with children's naïve theory on the quality of their exploratory play. Third, we study a prerequisite for learning from exploration: children's ability to make causal inferences. Last, we investigate how children's exploration yields knowledge by looking at the relations between children's exploratory play and domain-specific learning in both controlled and natural settings.

COLLABORATION UVA & NEMO: YOUNG EXPLORERS IN NEMO

Since the start of Curious Minds, the UvA research group has been working together with the Science Learning Center of science center NEMO. The collaboration is called Young explorers in NEMO (Kleuters aan zet in NEMO, http://www.e-nemo.nl/kleutersaanzet). Besides scientific studies in the museum setting, the collaboration has yielded several products for the practices of formal and informal science education. For example, for formal educational purposes teacher workshops were developed and implemented. These workshops focused on the importance of taking into account individual children's prior knowledge on science subjects, their (naïve) theories, in classroom education. For informal educational purposes, a guide was written with recommendations for developing science activities for preschoolers (Franse, Van Schijndel & Raijmakers, 2010). For writing the guide, NEMO and the UvA consulted the developmental psychological literature, held expert meetings with researchers from Curious Minds, and interviewed developers of preschool exhibitions from different European science museums. The resulting guide was used a point of departure for the development of NEMO's first exhibition exclusively for the preschool age group: Young explorers in NEMO.

Young explorers in NEMO ran at the science center on weekends and holidays from January 2010 until December 2011. The exhibition was developed based on the expertise of NEMO's in-house exhibition developers and the guide's recommendations, but also on the basis of outcomes of studies of the UvA research group. First, in the exhibition preschoolers were explicitly offered science content. The theme of shadows was chosen: a theater show and an exhibition space were developed to illustrate a number of physical principles related to shadows. For example, one principle concerned the relation between object size, the distance of an object to the light source, and shadow size. The level of difficulty in illustrating this principle was based on UvA group studies investigating preschoolers' naïve theories on shadow size. A second choice in developing the exhibition was to encourage meaningful exploration. The emphasis was laid on children's acquisition of process skills: the exhibition space contained interactive exhibits, some of which, for example, were explicitly designed for prediction to precede testing. In the development of exhibits, the finding of the UvA group that preschoolers' exploration is positively affected by evidence conflicting with their naïve theory was applied. A last choice in developing the exhibition was to stimulate parents to guide their children's learning process. Child and parent could only enter the exhibition together, they were addressed as a team by the explainer and exhibit labels, and some of the exhibits were explicitly designed for child and parent to engage with together. The emphasis on parent guidance was motivated in part by UvA group studies demonstrating positive effects of parent guidance on preschoolers' exploratory play.

THESIS OUTLINE

This thesis describes six empirical studies. The first two studies (Chapter 2 & 3) primarily focus on preschoolers' exploratory play. The third study (Chapter 4) concerns children's naïve theories in the field of science. The fourth study (Chapter 5) concerns a crucial skill in learning from exploration: the ability to make causal inferences. The fifth and sixth study (Chapter 6 & 7) bring together these topics by researching preschoolers' naïve theories, exploratory play, and causal learning. The first, second, and sixth study (Chapter 2, 3 & 7) were performed in natural settings, while the third, fourth, and fifth (Chapter, 4, 5 & 6) study were performed in controlled settings.

In the first two studies (Chapter 2 & 3) we investigated effects of adult guidance on preschoolers' exploratory play. The first study (Chapter 2) focuses on the effect of a sciencing program on 2- to 3-year-olds' exploration in the sandpit area of a daycare center. The second study (Chapter 3) focuses on the effects of adult guidance on 4- to 6-year-olds' exploration at exhibits in a science museum. The first experiment was performed during closing hours of the museum and examined which adult coaching-style resulted in the highest level of exploration. The second experiment was performed during opening hours of the museum and examined the effect of informing parents about an effective way of coaching on preschoolers' exploration. In both the study in the daycare center setting, and the study in the science museum setting, the Exploratory Behavior Scale was used to quantify children's exploration.[5]

In the third study (Chapter 4) we investigated 6- to 12-year-olds' naïve theories on prenatal development. We distinguished two sub-domains of prenatal development, the shape of the body and bodily functions, and examined whether children's knowledge in these sub-domains is coherent or fragmented. In addition, we studied whether doing a generative task, such as drawing, increases the coherence of children's theories.

In the fourth study (Chapter 5) we investigated a prerequisite for learning from exploration: children's ability to make causal inferences. We described the development of this ability by investigating individual differences in the type of inferences 2- to 5-year-olds use.

In the fifth and sixth study (Chapter 6 & 7) we investigated 4- to 6-year-olds' naïve theories, exploratory play, and causal learning. Both studies focus on preschoolers' naïve theories in the domain of shadow size. In the fifth study (Chapter 6) we examined the effect of evidence conflicting with children's naïve theory on the quality of their exploratory play. In addition, it was investigated how children's naïve theories and quality of play are related to their learning. In the sixth study (Chapter 7) we examined relations between different types of parent explanation, and preschoolers' exploratory play and learning in a science museum. In this study, the Exploratory Behavior Scale was used to quantify children's exploration.

At the moment of publication of this thesis all empirical chapters are in revision, published in, or submitted to international peer-reviewed journals. To acknowledge the important contributions of the co-authors a list of references is presented below:

- Chapter 2: Van Schijndel, T. J. P., Singer, E., Van der Maas, H. L. J., & Raijmakers, M. E. J. (2010). A sciencing programme and young children's exploratory play in the sandpit. *European Journal of Developmental Psychology, 7*(5), 603-617.
- Chapter 3: Van Schijndel, T. J. P., Franse, R. K., & Raijmakers, M. E. J. (2010). The Exploratory Behavior Scale: Assessing young visitors' hands-on behavior in science museums. *Science Education, 94*, 794–809.
- Chapter 4: Van Es, S. E., Van Schijndel, T. J. P., Franse, R. K., & Raijmakers, M. E. J. *Children's mental models of prenatal development.* Manuscript submitted for publication.
- Chapter 5: Van Schijndel, T. J. P., Huijpen, K., & Raijmakers, M. E. J. *Development of causal learning in 2- to 5-year-olds: Multiple age-related types of causal inference.* Manuscript in revision.
- Chapter 6: Van Schijndel, T. J. P., Visser, I., Van Bers, B. M. C. W., & Raijmakers, M. E. J. *Preschoolers perform more unconfounded experiments after observing evidence conflicting with their naïve theory.* Manuscript in revision.

- Chapter 7: Van Schijndel, T. J. P., & Raijmakers, M. E. J. *Parent explanation and preschoolers' exploratory behavior and learning in a shadow exhibition.* Manuscript submitted for publication.

Other papers related to this thesis:

- Bonawitz, E. B., Van Schijndel, T. J. P., Friel, D., & Schulz, L. E. (2012). Children balance theories and evidence in exploration, explanation, and learning. *Cognitive Psychology 64*, 215–234.
- Van Es, S. E., Van Schijndel, T. J. P., Franse, R. K., & Raijmakers, M. E. J. (2009). Children's thoughts on unborn babies, Representational redescription in preconceptions of children on fetal development. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (pp. 112-117). Austin, TX: Cognitive Science Society.

NOTES

1. This thesis brings together different fields of research, such as the field of developmental psychology and the field of visitor studies, and chapters are written for international journals in different fields. Therefore, the term "learning" is used in different manners. This footnote clarifies the use of the term in the different chapters. First, we talk about "science learning", "formal/ informal learning", and "learning in the field of science" to refer to a broad range of cognitive, affective, social, and behavioral learning outcomes (e.g. Brody, Bangert & Dillon, 2008; Mainly Chapter 1 & 8). As this thesis focuses on investigating cognitive learning outcomes, the terms "learning", "domain-specific learning", and "causal learning" are used to refer to children's knowledge acquisition in specific domains of science (Mainly Chapter 1, 6, 7 & 8). Last, in Chapter 4, the term "causal learning" does not refer to children's knowledge acquisition in a specific domain, but to a prerequisite for this process to take place: children's capacity to make causal inferences.
2. No general science programs for preschoolers had been developed, but the Freudenthal Institute for Science and Mathematics Education had developed "SamenRekenen", a preschool program focused on math development (Van Eerde, Peltenburg, Van den Boer & Nelissen, 2009).
3. Prof. Dr. Maartje Raijmakers is the primary investigator of the UvA research group.
4. In this thesis, the terms "exploratory play", "exploratory behavior", and "exploration" are used interchangeably.
5. The Exploratory Behavior Scale (EBS) is used for assessing preschoolers' exploration in the studies described in Chapter 3 and 7. The EBS consists of three levels: passive contact, active manipulation, and exploratory behavior. In the study described in Chapter 2, an extended version of the EBS, the Exploratory Play Scale (EPS) is used. The EPS consists of four levels: in this scale the third level is extended with construction behaviors, and the fourth level contains object replacement behaviors.
6. In this thesis, the terms "(naïve) theory", "rule" and "mental model" are used interchangeably to refer to children's coherent knowledge or ideas in specific domains in the field of science. The use of the term "naïve theories" in this thesis should not be confused with Wellman & Gelman's (1992) description of foundational theories of core domains, as the latter theories call on more elaborate and integrated sets of beliefs.