Science learning in informal contexts

Behavioral studies on children's knowledge of natural phenomena and family learning in the museum

Franse, R.K.

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1

General Introduction

1.1 SCIENCE MUSEUMS[1]: VENUES FOR FAMILIES TO ENGAGE WITH SCIENCE

Science and technology are essential for today's daily lives and society (Irwin & Michael, 2003; Krapp & Prenzel, 2011; Millar & Osborne, 1998). In knowledge-driven democracies, like the Netherlands, it is of great importance that a broad group of people can participate in informed discussions about scientific developments and technological innovations (Hazelkorn et al., 2015). For knowledge-based economies, a widespread interest in science, technology, engineering and mathematics (STEM) is important for the influx of students in vocational and higher STEM education (Osborne, Simon, & Collins, 2003; Sjøberg & Schreiner, 2010). In daily life, scientific knowledge and reasoning help us in making informed and balanced decisions (Krapp & Prenzel, 2011; PISA, 2016). The significance of getting young people interested and involved in science is therefore widely supported by governments, industry and science education communities (Archer et al., 2012). However, a body of evidence shows that young people's interest in science lags behind other school subjects (Osborne & Collins, 2001; Sjøberg & Schreiner, 2010), whereas science interest is formed at a young age (Archer et al., 2012).

Recent research shows that not only the formal learning context (primary and secondary education) has an impact on children and adolescents' science attitudes, but that the family context also determines the role that science will play in life. Following Bourdieu, (1997) who refers to *cultural capital* as a complex of knowledge, skills and attitudes that make up the development of cultural baggage, the literature also refers to *science capital* (Archer et al., 2012). To develop science capital, it is not only important that young people gain knowledge about science and technology, but also that they develop ways in which they can reason about this knowledge and that they are able to connect it to their own context. Science capital is largely determined by the family context, it is a way of perceiving, thinking, and acting that is shaped in the social structure of the family. Hence, next to formal, the informal learning context plays an important role in shaping children's science attitude.

Science museums are venues where families can engage with science and technology and get inspired to learn about science (Bell, Lewenstein, Shouse, & Feder, 2009; Falk et al., 2012). Science museums united in the European network of science centres and museums (Ecsite) aim at strengthening citizens' engagement and interaction with science, *"because science is an indelible part of culture, because citizens find empowerment with scientific knowledge and because experiential learning opens doors*" (Achiam & Sølberg, 2017). Bell et al. (2009) emphasize that in science museums families not only learn by gaining knowledge and concepts, but also by experiencing a different way of looking at the world: by asking questions and by investigating. Demonstrating that these learning objectives are actually being achieved is by no means simple. Given its free-choice nature, measuring learning in a science museum context is challenging (Pattison, Gutwill, Auster, & Cannady, 2019).

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[1] I, as the author of this dissertation, am a scientist practitioner working as a senior project manager at NEMO Science Museum in Amsterdam.

Insights from scientific research can inform science museum practice (Sobel & Jipson, 2015). Both insights that arise from practical questions (e.g., “Is evidence description an effective guidance strategy to enhance learning through investigation?”), as well as insights that arise from more fundamental questions (e.g., “Does parental pre-knowledge impact parent-child interaction?” or “What knowledge do children have about buoyancy?”), can be useful in designing museum programs. The body of literature studying learning in science museums has grown the last decades (Andre, Durksen, & Volman, 2017). Yet, there is still a lot to learn about learning through investigation at open-ended exhibits[2] and the factors that might impact this learning. The research described in this dissertation is aiming at a better understanding of learning through investigation in the museum, in order to contribute to in-depth museum learning experiences.

1.2 FAMILY LEARNING THROUGH INVESTIGATING NATURAL PHENOMENA

When entering a science museum, you step into a dynamic world where people are excited, talk out loud, quickly switch from one activity to another, and where a hands-on approach to learning governs. Typical for science museums are the interactive exhibits that foster the investigation of natural phenomena (Gutwill & Dancstep, 2017). Many of the natural phenomena presented in science museums, such as gravitation, light, buoyancy, and object movement, are familiar for people. From an early age on, people experience natural phenomena in daily life, which results in experiential knowledge. At the same time, complex physical concepts underlie these natural phenomena, which cannot easily be understood by experiential knowledge alone. Science museums often present everyday phenomena in order to elicit curiosity, raise questions, and encourage visitors to investigate phenomena (Achiam & Sølberg, 2017; Bell et al., 2009). Ensuring that visitors fully understand the scientific explanation of complex physical concepts is for many science museums not the main objective. These museums do aim at facilitating visitors to construct knowledge in interaction with the exhibits and each other, and fostering science interest, science enjoyment, and an inquiry attitude (Allen, 2004). Interactive exhibits can encourage visitors to explore[3] and discover (McLean, 1993; Rennie & McClafferty, 1996), and can elicit social interaction between child and parent (Blud, 1990).

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[2] Open-ended exhibits refer to interactive exhibits that have multiple options, give families the opportunity to actively create experiments themselves, and therefore support the investigation process (e.g., Active Prolonged Engagement exhibits, Humphrey & Gutwill, 2005). To compare: discovery exhibits (Hein, 1998), another type of interactive exhibit, explain and offer scientific content leading the visitor to canonical correct scientific ideas (Gutwill, 2008).

[3] To explore, to engage, to interact, to experiment, to inquire and to investigate are all verbs used in museum practice and museum literature to describe the active behavior of visitors at an interactive exhibit. In practice and literature these terms are sometimes used interchangeably, although there are differences in definition. Engaging or exploring refers to a more open approach of getting to know the material and experiencing the phenomenon. Investigating or inquiring refers to a more systematic approach of ‘doing science’, that is, by asking questions and testing hypotheses. To better match the scientific literature, we choose to use different terms in Chapter 3 (investigate) and Chapter 4 (inquire), however, both are referring to a systematic hypothesis-driven approach, and can be interpreted as interchangeably.

In education, different types of learning outcomes are distinguished. Bloom (1956), for example, distinguished cognitive, affective, and psychomotor educational objectives (e.g., knowledge and valuing). In the informal learning context, a widely-acknowledged, bottom-up literature review (Bell et al., 2009), resulted in a framework to describe educational outcomes. This framework distinguishes six strands of science learning: sparking and developing interest and excitement (strand 1), understanding science knowledge (strand 2), engaging in scientific reasoning (strand 3), reflecting on science (strand 4), engaging in scientific practice (strand 5), and identifying with the scientific enterprise (strand 6).

Combining multiple learning objectives in a learning experience, such as multiple above-described strands, is not self-evident, and has the interest of museum practitioners (Allen, 2002, 2004) as well as researchers of informal (Gutwill, 2008) and formal (Alfieri, Brooks, Aldrich & Tenenbaum, 2011) learning contexts. In formal context, it has been shown that investigation of an open-ended task often leads to prolonged investigation, but limited knowledge gain (Alfieri et al, 2011; Kirschner, Sweller & Clark, 2006; Klahr & Nigam, 2004). This also seems the case for the museum context: open-ended investigation leads to involvement and enjoyment (strand 1), but happens at the expense of the quality of investigation (strand 2 and strand 3), and therefore hampers knowledge and skill acquisition (Gutwill, 2008). In a formal school context, guidance by teachers significantly contributes to the effectiveness of pupils' concept learning through investigation (Alfieri et al., 2011; Lazonder & Harmsen, 2016). However, the museum and school context are fundamentally different in a variety of ways. The autonomy and motivation of the learner differ, differences in pre-knowledge seem larger between individuals in an informal context. Moreover, the assessment, social context, learning goals, and learning materials in an informal context differ importantly from what is accepted in, for example, a primary and secondary schools (Callanan, Cervantes, & Loomis, 2011; Falk & Storksdieck, 2005; Hooper-Greenhill & Moussouri, 2000). Aiming to better understand learning experiences in science museums, we designed three empirical studies about learning from and about everyday science.

Four research themes are central to this dissertation: 1) concept development and knowledge structure of natural phenomena, 2) learning through investigation in science museums, 3) the impact of person characteristics on family investigation and parent-child interaction, 4) minimal guidance strategies for museum educators. In the following section (§1.3) we first place these four themes in a theoretical framework. Subsequently, we will further introduce the research questions and designs of the studies (§4).

1.3 RESEARCH FRAMEWORK

1.3.1 Conceptual Development and Knowledge Structure of Natural Phenomena

Natural phenomena surround us in daily life, often from early age on. Children's knowledge of natural phenomena develops over time (e.g., Edelsbrunner, Schalk, Schumacher, & Stern, 2015;

Flaig et al., 2018; Hardy, Jonen, Moller, & Stern, 2006; Schneider & Hardy, 2013), and is based on heterogeneous sources of information: frequent perceptual experiences, observation of distinct exemplars, and more abstract knowledge. These heterogeneous sources are found in both informal and formal learning contexts, and can lead to different types of knowledge representations (diSessa, Gillespie, & Esterly, 2004; Duit, 2009; Hofman, Visser, Jansen, & van der Maas, 2015; Janke, 1995; Schneider & Hardy, 2013; Straatemeier, Van der Maas, & Jansen, 2008; Wilkening, 1981; Wilkening & Anderson, 1982). Concept knowledge resulting from heterogeneous information is of great interest for cognitive science (Machery, 2010). Two important, interrelated, and highly-debated questions are: “How is knowledge organized?” (knowledge structure) and “What the best way is to assess children’s concept knowledge?” (measurement) (diSessa, et al., 2004; Straatemeier, et al., 2008; Vosniadou, 2008). We investigate the phenomenon of floating and sinking (**Chapter 2**) as an interesting case study in concept knowledge originating from natural, heterogeneous information sources.

Different types of methodologies have been used in studying children’s concept knowledge. Generative methods, such as drawing or modeling, forced-choice questionnaires, and open-ended interviews. When discussing the pros and cons of methodologies in the literature, topics argued are: establishing objective scoring (Straatemeier et al., 2008), measuring response coherency (Van Schijndel, Van Es, Franse, Van Bers, & Raijmakers, 2018b), limiting response possibilities, overestimating performance (Vosniadou, 2008), and confusing children due to unnatural assessment situations (Siegal, 1997). We use a forced-choice questionnaire and a structured interview in studying children's knowledge of floating and sinking (**Chapter 2**), to be able to assess the coherency of children’s representations over different tasks and to assess both explicit (e.g., verbalized explanations) and implicit (forced-choice predictions without explanations) knowledge representations.

1.3.2 Learning through Investigation in Science Museums

Investigation, inquiry and scientific reasoning are all terms used in developmental psychology and the educational sciences to describe a range of behavioral activities and reasoning processes (e.g., predicting, experimenting, measuring, and explaining, Pedaste et al., 2015), that are similar to the systematic approach that scientists use to describe and explain the world around us (Allen & Gutwill, 2009; Kisiel, Rowe, Vartabedian & Kopczak, 2012; Zimmerman 2005). Learning through investigation is just as multifaceted. It can result, in the long term, in the acquisition of procedural skills, reasoning strategies, science attitude and conceptual understanding. Measuring learning through investigation in informal settings, like in museums, is not standardized, and can be considered a complex undertaking. Families’ learning through investigation in museums has been studied from different theoretical perspectives with different measurement methods (Bell et al., 2009).

The individual-centered cognitive developmental perspective on learning in museums is rooted in the tradition of Piaget (1936), Wellman and Gelman (1992), and Gopnik (1996), among others (Callanan & Valle 2008). Development is seen as change in the child's mind, triggered by observations of the world and interactions with other people. Parents are positioned as facilitators of the child's learning (i.e., positioned outside the child's learning system). Learning manifests itself through acquired concepts and theories (Callanan & Valle, 2008), but also in 'in situ' behavior, or in motivation-related gains, such as the child's attitude towards learning or curiosity. Research based on this perspective takes the individual child as unit of analysis. The sociocultural perspective on the other hand, is focused on learning in context. It is rooted in the tradition of Bronfenbrenner (1977), Vygotsky (1978), and Rogoff (2003), among others (Callanan, Castañeda, Luce, & Martin, 2017). Development is seen as a dynamic system of mutually acting and reacting people. Learning manifests itself in the way people interact with the world and each other by exchanging verbal and non-verbal information (Callanan & Valle, 2008). Instead of taking a facilitator role, parents are now positioned within the learning system. Research from this perspective often takes a group of people (e.g., a family) as unit of analysis, and uses more situated measures to study people's spontaneous engagement in learning settings (Rogoff, 2003).

In the informal learning literature, three categories of indicators for learning through investigation at open-ended exhibits are reported: manipulations, conversations, and post-visit learning outcomes. The way to investigate natural phenomena with open-ended exhibits is by manipulation of multiple variables by designing experiments. The extent to which visitors' manipulations provide relevant and reliable information depends on the quality of the experiments. A second indicator of learning through investigation is the verbal interaction between family members. Different aspects of families' conversations have been studied. For example, the reasoning *content*, quantified as naming properties of the scientific phenomenon at hand (e.g., Leinhardt, Crowley, & Knutson, 2002; Palmquist & Crowley, 2007), or as sources of content (e.g., Tunnicliffe, 2000; Zimmerman, Reeves, & Bell, 2010). Or, as another example, the reasoning *skills*, quantified as elements of scientific reasoning (Gutwill & Allen, 2010, Kisiel et al., 2012) or types of explanation (Callanan & Jipson, 2001; Crowley et al., 2001a; Szechter & Carey, 2009; Van Schijndel & Raijnmakers, 2016). A third indicator of learning through investigation is a cognitive learning outcome. Post-activity learning outcomes (i.e., what someone remembered, learned or understood) can be considered the traditional way of measuring learning.

In the second study of this dissertation (**Chapter 3**), we combined the socio-cultural and cognitive developmental perspectives on learning in studying families' learning through investigation at an open-ended exhibit on the museum floor. We considered learning in natural situations where all family members contribute to a shared learning situation by taking the family as unit of analysis in quantifying families' manipulations, reasoning *skills*, and reasoning *content*. But, we also considered learning to be an individual effort whereby information from the same shared learning situation can be perceived and processed differently due to individual differences. Therefore, in this study, we investigated the impact of person characteristics on family learning.

In the third study (**Chapter 4**), we also combined both perspectives on learning. To study the effect of parental content knowledge on parent-child interaction during an inquiry activity in a lab setting, we used manipulations and conversations as indicators for learning through investigation. In this study, manipulations were measured by 'who acted': the child or the parent alone, or child and parent collaboratively. Different conversational indicators were used in this study, we focused on both parents' scaffolding (e.g., asking open ended questions) and parents' and children's scientific reasoning (e.g., formulating hypotheses and interpreting results). Additionally, to investigate if changes in parent-child interaction due to parental pre-knowledge were also related to children's learning outcomes, a post-activity measure was included.

1.3.3 Person characteristics and Learning through Investigation

In the museum literature, person characteristics, such as age, gender, and educational background, are often reported to give insight into the population that is studied. Science museum visitors usually are not a cross-section of a countries' population, and this is a point of concern when aiming for an inclusive museum. For example, families visiting NEMO Science Museum do not represent the Dutch population: on average, parents are higher educated, and children enjoy science to a higher extent (see **Chapters 3** and **4**).

In addition to giving insight into the population studied, some research investigated the relation between person characteristics (e.g., Geerdts, Van De Walle & LoBue, 2015; Nadelson, 2013; Siegel, Esterly, Callanan, Wright, & Navarro, 2007; Tare, French, Frazier, Diamond & Evans, 2011) and visitors' informal learning behavior. In the third study of this dissertation (H4), we investigated the role of parental pre-knowledge in parent-child interaction in an experimental design. In addition, we investigated the relations between person characteristics and knowledge development (**Chapter 2**), and learning (**Chapters 3** and **4**). In the first study (**Chapter 2**), we included children's age as a proxy for experience and developmental level. In the second (**Chapter 3**) and third (**Chapter 4**) study, children's experience and developmental level were separated by measuring specific cognitive skills, that is, working memory (**Chapters 3** and **4**) and reasoning abilities (**Chapter 3**). Other person characteristics measured were science enjoyment (**Chapters 3** and **4**), interest (**Chapters 3** and **4**) and attitude (**Chapter 4**), gender (**Chapters 3** and **4**) and educational level (**Chapters 3** and **4**).

1.3.4 Guidance and Learning through Investigation

Every day large numbers of people visit science museums. For example, NEMO Science Museum in Amsterdam welcomes 1,800 visitors on an average day, with peaks towards 4,000 visitors during the school holidays, in 2019. Museum exhibits must be prepared for such large amounts of different visitors: not only in terms of exhibit robustness (Monkey proof) and user accessibility (Allen, 2004) but also in terms of learning. Considering the individual differences between visitors, there might something to be gained if general programs could be more adapted to the needs and preferences of individual visitors.

In a way, learning experiences are already adapted to the individual. In the museum context, some parents guide their children during investigation by giving individual attention and support (Ash, 2004a; Crowley & Callanan, 1998; Pattison & Dierking, 2013). The accompany of a parent, compared to investigating alone or with peers, goes together with longer and deeper investigations (e.g., hypothesis-driven) (Crowley et al., 2001a; Gleason & Schauble, 1999). Within this collaborative and dynamic learning process (Legare, Sobel, Callanan, 2017), parent and child differences in knowledge, reasoning skills, and interest can result in opportunities for parents to scaffold their children's learning (Alfieri et al., 2011; Wood, Bruner, & Ross, 1976). However, also for parents, subjects presented in the museum are sometimes new or complex, whereby parents lack specific content knowledge that could enrich verbal interaction (Knutson & Crowley, 2010). This means that parents during joint investigations not only take on the role of facilitator of the child's learning process, but also the role of learner (Falk, 2009; Siegel et al., 2007). Little research has been done into the effect of parents' prior content knowledge on parent-child interaction during investigation in the museum. Therefore, in the third study of this dissertation (**Chapter 4**), we will investigate this research topic in an experimental design.

In addition to parents, museum educators could also play a role in adapting the museum offer by guidance. In the school context, guidance has shown to be effective to improve learning through investigation. For example, learning through open-ended investigation has been shown to benefit from scaffolding techniques as modeling, questioning, giving hints, instructing, or explaining (Alfieri et al., 2011; Van de Pol, Volman & Beishuizen, 2010). Whether this also applies to the museum context, cannot simply be assumed. Guidance in a museum context is constrained by specific factors that characterize informal learning contexts. In addition to a large heterogeneous group of people they hardly know, museum educators have to deal with a museum offer that is very diverse in content and degree of open-endedness. Moreover, most museum educators have very different educational backgrounds than school teachers. A standardized preparatory training such as a teacher training for primary school teachers, in which attention is paid to scaffolding techniques, is not available for museum educators (Schep, Van Boxtel, & Noordegraaf, 2018; Uyen Tran & King, 2007). Uyen Tran and King (2007) developed a theoretical framework that distinguishes different domains in which science museum educators can develop, based on informal science education literature and focus group discussions with practitioners and researchers. However, concrete guidance strategies are not presented. In many cases, science museum educators learn on-the-job and by participating in internal training sessions, which are often linked to specific visitor programs. Exceptions aside (e.g., the REFLECTS professional development project, Ash, Lombana, & Alcala 2012; and the REVEAL facilitation model, Pattison et al., 2018), those sessions typically focus on predetermined disciplinary content or scripts with standardized questions, rather than learning museum educators to respond to families with adaptive guidance.

In addition to the above, little research investigated museum educator guidance strategies for fostering learning through investigation in the museum during unstructured visits (Pattison et al., 2017; Pattison et al., 2018). Therefore, insights into guidance strategies that parents use in a museum context might be informative. Based on earlier research of parent-child interactions during every day scientific thinking (e.g., Callanan & Jipson, 2001; Crowley et al 2001a; Fender & Crowley 2007), Van Schijndel and Raijmakers (2016) analyzed parents' guidance strategies when visiting a shadow exhibition with their preschooler, in NEMO Science Museum in Amsterdam. Especially describing evidence (e.g., talk about exhibit features or observations) was shown to be positively related to the level of children's exploratory behavior. To investigate whether this guidance strategy can be generalized to museum educators who guide heterogeneous family groups during an unstructured museum visit, and to make causal claims about the relation between describing evidence and open-ended investigation, follow-up research with an experimental design was needed. This research was performed as part of the second study of this thesis (**Chapter 3**).

1.4. THESIS OUTLINE

1.4.1 Research questions

This dissertation describes three experimental studies that, each in their own way, shed a light on learning from and about everyday science. Both questions about children's knowledge representations of natural phenomena, and the impact of parental knowledge on parent-child interaction, which contribute to more fundamental research questions, have been studied (**Chapters 2** and **4**), as well as questions motivated by practice, about person characteristics (**Chapters 3** and **4**) and guidance strategies (**Chapter 3**) that might impact families' learning through investigation in a science museum. The first study (**Chapter 2**) investigates knowledge representations of a natural phenomenon, in particular buoyancy, in children of different ages. Natural phenomena surround us in daily life, and can be encountered in a science museum. What is the structure of the representations that children have of these phenomena? How do knowledge representations, that origin from heterogonous information sources, differ between age groups? Do different types of experimental methodologies trigger different type of knowledge representations? And are these knowledge representations equivalent in different contexts? The second study (**Chapter 3**) examines learning through investigation. What is the potential of families' learning through investigation at an open-ended exhibit in a science museum? Are families' manipulations informative? What is the quality of families' conversations during investigations: do they reason scientifically by formulating hypotheses and explanations, and are these statements scientifically sound? In addition to this detailed analysis of families' learning through investigation, this second study also examines how person characteristics, and minimal guidance strategies performed by museum educators, impact on family learning. The third study (**Chapter 4**) examines the impact of parent pre-knowledge on parent-child interaction. Does parental pre-knowledge of an inquiry activity that a family investigates, change parents' behavior? And does this change in behavior impact on children's learning? Pre-knowledge is one of the many person characteristics by which museum visitors can differ from one another. This third study additionally examines relations between several other person characteristics and parent-child interaction during investigation.

1.4.2 Research designs

Different research designs have been applied to study the research questions. The first study (**Chapter 2**) is a cross-sectional, developmental study, which investigated the development of knowledge representations of buoyancy in children aged four to twelve. The statistical methods used in this study (Latent Class Regression and Latent Class Models) allowed for accounting for individual differences in knowledge about buoyancy within age groups. The study was designed as a controlled lab study with a strict protocol, and was carried out at a primary school. 139 primary school students participated in this study. The second study (**Chapter 3**) is an in-depth field study, in which the potential of families' learning through investigation was studied in detail at an open-ended exhibit in the museum. This research approaches the natural situation of a family visiting a science museum, within the constraints that experimental research requires. The study was conducted at NEMO Science Museum during opening hours at an exhibit that is part of the permanent collection. 104 family teams of one parent and two children (eight to twelve year-olds) participated in the study. The third study (**Chapter 4**), which investigated the effect of parental pre-knowledge on parent-child interaction, can be classified as in-between a lab and a field study. The study was conducted in NEMO R&D, an enclosed space on the exhibition floor of the museum, where participants can participate in research under relatively quiet conditions. The interaction between parent and child was observed while they jointly investigated an inquiry activity that showed similarities with the interactive exhibits in the museum. The participants in the study were museum visitors who, when approached on the spot, decided to participate in the study. 105 parent-child dyads with children aged 8-12 participated.