Science learning in informal contexts

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

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Summary and General discussion

The research described in this dissertation stems from an interest into how people learn from and about everyday science. In three empirical studies (chapters 2, 3 and 4) different aspects of science learning have been studied: the knowledge representations of a natural phenomenon (study 1), the effect of minimal guidance strategies on families' learning through investigation (study 2) and the impact of parental pre-knowledge on parent-child interaction during investigation (study 3). This last chapter (chapter 5) summarizes the main findings of these three studies and then discusses the outcomes in relation to the scientific relevance, the study limitations and the directions for future research. Finally, the relevance of the findings to museum practice is discussed.

5.1 SUMMARY OF MAIN FINDINGS

In the first study (**chapter 2**), we have investigated children's pre-knowledge of floating and sinking. Children can learn about buoyancy by means of various information sources: physical experiences, observing specific situations, reading books, or through conversations with others. The cognitive science literature discusses how knowledge that results from heterogeneous information sources is organized (DiSessa, Gillespie, & Esterly, 2004; Vosniadou, 2008) and how this knowledge is best assessed (Straatemeier, Van der Maas, & Jansen, 2008; Van Schijndel, Van Es, Franse, Van Bers, & Raijmakers, 2018b). We systematically investigated the coherency of children's buoyancy representations for multiple contexts (sets of objects) using multiple tasks (multiple-choice questions and a structured interview with open questions). Four- to twelve-year old children (N = 139) were asked to predict buoyancy for three sets of objects and to explain buoyancy of the predicted floaters and sinkers. The sets of objects differed in buoyancy-related properties. Buoyancy of the indistinctive objects (cubes made of indistinct materials) could only be predicted based on perceptions of the cube's mass and volume, while buoyancy of the material objects (wooden and metal cubes) and the exemplar floaters and sinkers (e.g., a pebble, a coin, a wood stump) could also be predicted based on material knowledge and factual-knowledge. The results of the first study revealed multiple knowledge representations of buoyancy within, and between children, depending on task demands, and types of objects to classify. By using multiple tasks in assessing children's knowledge representations, we have shown that different question types triggered different knowledge. That is, prediction questions triggered more advanced two-dimensional strategies (mass + volume), and explanation questions triggered more, less-advanced one-dimensional strategies (mass only). In addition, we have shown that predictions and explanations were not consistent within individuals. By assessing children's knowledge representations for multiple contexts (sets of objects), we demonstrated that different object properties triggered different knowledge. That is, indistinctive objects triggered rule-based knowledge (one or two-dimensional strategies), and exemplary objects mainly triggered factual-knowledge. In addition, in predicting the buoyancy of the material-based objects we found evidence for an interaction between different types of knowledge.

In the second study (**chapter 3**) we have investigated the effect of minimal guidance strategies by museum educators on families' learning through investigation at an interactive exhibit in a science museum. The effectiveness of learning through investigation, and the factors that contribute to this effectiveness, are topics of interest in both formal and informal science learning literature. We studied the effect of minimal guidance strategies on family learning with an experimental design. In the control condition, families investigated on their own. In the experimental condition, families were accompanied by a museum educator who applied one of two minimal guidance strategies: describing evidence or giving explanations. An important difference between the two strategies is that in describing evidence relevant task aspects or observations are only described, whereas in giving explanations the scientifically correct causal relationship between them is explained. Family teams (N = 104) of one parent and two eight- to twelve-year old children investigated the phenomenon of object motion by designing and performing experiments considering multiple variables (different characteristics of objects rolling down on a ramp). As indicators for learning we performed detailed observations of families' manipulations and conversations during investigation. The proportion of control of variable experiments performed was used as a measure of manipulation quality. Families' conversations during investigation were studied for reasoning *skills* (formulating hypotheses and interpreting results) and reasoning *content* (object motion and reliable experiments). The results of the second study showed that families were able to investigate in a meaningful way at an interactive exhibit in a science museum. Families controlled their experiments and formulated hypotheses and causal explanations. Families not only discussed the investigated phenomenon of object motion, but also had meta-conversations about the reliability of their experiments. Although largely manipulations and conversations were meaningful they did not necessarily lead to correct hypotheses and conclusions about the phenomenon: families often related object properties to object motion in a scientifically incorrect way. However, it was demonstrated that minimal guidance strategies by museum educators can contribute positively to reduce scientifically incorrect conclusions about the relation of object motion and object mass. This effect was shown for both minimal guidance strategies, i.e. describing evidence and giving explanations.

In the third study (**chapter 4**) we have investigated the effect of parental pre-knowledge on parent-child interaction during investigation. In addition, we studied the relation of parents' and children's person characteristics and parent-child interaction. The possible relation of individual differences of parents and children with effective parent-child interaction and investigation in the museum, is of interest to developmental and education researchers, and museum practitioners. We have studied the interaction of parent-child dyads (N = 105) with eight- to twelve-year old children while they investigated a black box, an activity that invites participants to inquire about causal relations and perform model-based reasoning. As indicators for parent-child interaction we studied dyads' manipulations for who acted (the child or parent alone, or in collaboration), and parent and child talk for elements of scientific reasoning and scaffolding (e.g., asking open-ended *wh*-questions). In addition, parents' and children's solution accuracy of the inquiry problem was studied as a learning outcome. The results of the third study showed that parental pre-knowledge facilitated parental guidance, such that parents asked more closed questions and more open-ended *wh*-questions. Parental pre-knowledge also led to an increase of children's explanations. Moreover, parental pre-knowledge improved children's learning outcomes without parents giving more explanations. We have also shown that person characteristics of parents and children were related to parent-child interaction: children's gender and the interaction of parent's gender and parental pre-knowledge was related to the cooperation between parent and child. Additionally, children's self-reported inquiry attitude was related to child talk during inquiry, such that children with a higher inquiry attitude asked fewer closed questions and more open-ended questions.

5.2 GENERAL DISCUSSION

This dissertation addresses different research questions about science learning in the informal context, and includes three stand-alone studies. The studies have in common that we used an experimental design, quantitative measures, and that we applied multiple measurement methods in each study. The field of visitor studies lacks experimental, quantitative research (Allen, et al., 2007). This type of research focuses on the reproducibility of research insights and/or identifying causal relationships (Fu, Kannan, Shavelson, Peterson & Kurpius, 2016). To this end, we have assessed inter-rater reliability for all observational measures in this dissertation. A downside of quantifying data is that information is lost, leading to a limited representation of what actually happened. However, by using multiple methodologies, we have been able to quantify children's and adults' verbal and non-verbal behavior in great detail. Measuring in this way is labor-intensive due to video registering, transcribing and scoring verbal and nonverbal behaviors of larger populations ($N > 100$), and assessing inter-rater reliability. However, it does provide a more extensive insight in families' learning through investigation compared to, for example, administering a post-knowledge test. For example, in study 2, we obtained a detailed picture of families' learning through investigation by quantifying their performed CVS experiments, their verbalized scientific reasoning and (mis)conceptions, and their meta-level discussions about investigation. As the context is important for learning in the museum, to improve future generalizability of our results, we have developed research methods that are transferable to other phenomenon based open-ended exhibits.

In this dissertation, we build on different theoretical perspectives: an individual-centered cognitive developmental perspective on learning with the aim to study how individual differences in person characteristics impact children's and parent's knowledge and behavior (studies 1, 2, and 3), and a socio-cultural perspective on learning to study learning through investigation at the level of families in the museum context (study 2). The approach of drawing on methods and insights from the research field of categorization, a research field that is largely based on well-controlled lab studies, turned out to be a useful approach in studying children's representation of the natural phenomenon of buoyancy (study 1).

5.2.1 Children's knowledge representations of natural phenomena: the case of Floating & Sinking

Scientific relevance. In the cognitive science literature, it is debated how knowledge from heterogeneous information sources is organized: in terms of coherent representations or fragmented knowledge (diSessa, et al., 2004; Vosniadou, 2008). The results of the first study contributed to this discussion by showing that a more abstract context triggered coherent representations (rule-based knowledge) in children when predicting buoyancy, which has also been found for the phenomena shadow size (Van Schijndel & Raijmakers, 2016), and torque principle (Jansen & Van der Maas, 1997). In contrast, in a more daily-life context children's fragmented representations (factual-knowledge) were triggered in predicting buoyancy. A second discussion in the cognitive science literature concerns the way knowledge is best assessed, for example by multiple-choice questionnaires (Van Schijndel & Raijmakers, 2016; Shadow size), or interviews (Van Schijndel et al., 2018b). We have contributed to this debate by using multiple quantitative measures and by showing intra-individual differences in children's representations as a result of differences in contexts and tasks. Children showed more advanced representations when they were asked to predict buoyancy with multiple-choice questions compared to when they were asked to explain buoyancy during a structured interview. The finding that different measurement methods can lead to different results is in line with research studying children's representations of the earth (Straatemeier, et al., 2008), and prenatal development (Van Schijndel et al., 2018b), which led researchers to conclude that some measurement methods are more reliable than others. However, in chapter 2 we argue that different measurement methods relate to different types of knowledge representations, in agreement to the categorization literature (Ashby & Ell, 2001).

Study limitations and directions for future research. One of the challenges in studying children's knowledge representations, is the potential learning effect as a result of testing (Van Schijndel et al., 2018b). A fixed order of stimulus presentations, as in our study, potentially affects test outcomes. We presented the multiple object sets such that the number of relevant object properties increased during the experiment. As such we aimed at triggering properties of the objects it selves instead of properties of the earlier presented objects. In a follow-up intervention study presenting object types in a random order we replicated our findings concerning children's representations of buoyancy (Van Schaik, Slim, Franse, & Raijmakers, 2020). Secondly, giving explanations by children during the assessment could have a learning effect in itself. These in the literature called self-explanations (Williams & Lombrozo, 2010) could affect explanations of future object sets. From this perspective, it would be interesting to investigate whether and how explanations depend on the order in which children are asked to explain buoyancy of the three object sets.

5.2.2 Guidance strategies and family learning

Scientific relevance. An important question in the science museum literature is how family learning during unstructured museum visits can be best facilitated (Allen, 2004; Allen & Gutwill, 2009; Bell, Lewenstein, Shouse, & Feder, 2009; Crowley et al., 2001a; Dritsas, Borun, & Johnson, 1998; Falk & Storksdieck, 2005; Haden et al., 2014; Pattison & Dierking, 2012; Van Schijndel, Franse, & Raijmakers, 2010). Little quantitative research has been published on effective minimal guidance strategies to stimulate families' learning through investigation in the museum (Falk, 2004; Pattison et al., 2017; Uyen Tran, & King, 2007). Minimal guidance strategies, such as giving explanations (Crowley et al., 2001a), describing evidence (Crowley et al., 2001a), and asking open-ended *wh*-questions (Haden, 2010), are of interest to science museums as these strategies are less complex to implement compared to scaffolding. Scaffolding, an approach that is used to support student's inquiry learning in a school context (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Van de Pol, Volman & Beishuizen, 2010), requires a good insight into the student's initial situation. This insight into visitors' initial situation is difficult to achieve for museum educators given the short contact time, the large number of visitors they meet during a day, and the heterogeneous nature of the museum audience (e.g., age, educational level, pre-knowledge, visiting goals, motivation for learning). Moreover, minimal guidance strategies fit in with the informal character of learning in the museum, where visitor autonomy is considered a great asset (Barton & Tan, 2010; Falk & Dierking, 2000). In study 2 and 3 we studied in different ways the relation of minimal guidance strategies and family learning. An interesting point that emerged from both studies is that an improvement in domain-specific content knowledge can be attributed to minimal guidance strategies that do not specifically explain the phenomenon investigated. In study 2, both guidance strategies used by museum educators resulted in a decrease in families' incorrect conclusions about the phenomenon investigated (i.e., domain-specific content knowledge). Note that in using the describing evidence strategy the scientifically correct relationship between the effect (object acceleration) and the variables (object properties) was not mentioned by the museum educator. The finding that describing evidence turns out to be as effective for improving domain-specific content knowledge as giving explanations is relevant for the aim of stimulating learning through investigation. Firstly, research has shown that giving explanations can negatively affect families' investigative behavior (Gutwill, 2008). Secondly, the descriptions by the museum educator seem to facilitate the family conversations, which could be seen as self-explanations of the family members. A meta-analysis of self-explanation and learning showed that giving self-explanations, compared to guided explanations, results in a higher learning effect even when self-explanations were combined with guided explanations (Bisra, Liu, Nesbit, Salimi, & Winne, 2018). In study 3 we have shown that parents, without being trained in advance, spontaneously choose a non-explanation guidance style when having a knowledge edge compared to their child. Instead of sharing knowledge with their child by explaining, parents with pre-knowledge asked more open-ended *wh*-questions, resulting in children coming up with better solutions to the inquiry problem investigated. Similar to the describing evidence strategy (study 2), asking open-ended *wh*-questions (study 3) does reveal the scientifically correct relationship between the phenomenon (moving ropes), and the variables (the ropes and the fabric ring).

Study limitations and directions for future research. Since both studies (study 2 and study 3) have experimental design, we can conclude that there is an effect of minimal guidance strategies on family learning, and an effect of parental pre-knowledge on parental guidance and children's learning. However, the effect sizes may be smaller or bigger in natural settings. The designs of study 2 and 3 differ in certain ways from parent-child interaction during a free visit in the museum or at home. Possibly, parents and children investigate more focused when participating in scientific research, because they take research seriously or because they have committed themselves as a family to the activity (external motivations). During a free visit in the museum, guidance by a museum educator could have more impact if it helps the family to focus on investigation, but also could have less impact if families do not pay attention to the educator's remarks. Another limitation is the generalizability of the study outcomes to other contexts within the museum. The specific exhibit context may have influenced the observed effect. In both studies, a single exhibit was used to study guidance strategies and family learning, which is not uncommon in the visitor study literature (e.g., Benjamin, Haden, &Wilkerson, 2010; Crowley et al., 2001a; Van Schijndel & Raijmakers, 2016). However, it would be interesting to further study the effect of parental pre-knowledge on parental guidance in different contexts, that is, with other exhibits that include less familiar phenomena. Another interesting topic for future studies would be families' meta-conversations, for example about the reliability of performed experiments as was observed in study 2, as this is an under-investigated aspect of learning through investigation.

5.2.3 Individual differences and family learning

Scientific relevance. In family learning, individual differences can play a significant role due to age differences and the absence of a shared formal education history. Parent and child characteristics have shown to be related to family learning in the museum (e.g., Benjamin et al., 2010; Crowley, Callanan, Tenenbaum, & Allen, 2001b; Luce, Callanan, Smilovic, 2013; Siegel, Esterly, Callanan, Wright, & Navarro, 2007; Szechter & Carey, 2009; Van Schijndel & Raijmakers, 2016;). However, family learning in a museum context is complex, and subject to many other factors besides individual characteristics (e.g., co-visitors and museum staff, exhibition design, Falk & Storksdieck, 2005), and therefore effects of individual characteristics are not consistently found. For example, some studies showed parental talk to be related to children's age (Geerdt, Van de Walle, LoBue, 2015; Marcus, Haden, & Uttal, 2018), while other studies did not (Jipson & Callanan, 2003; Tenenbaum & Leaper, 2003), but the age ranges differ between these studies. In study 2 and study 3 we have investigated the impact of different person characteristics on family learning, where family learning included both the learning process during investigation (study 2 and study 3), and the learning outcomes from investigation (study 3).

Child characteristics. Interest and motivation are important preconditions for learning (Vansteenkiste, Simons, Lens, Sheldon & Deci, 2004), children's science attitude relates to lifelong learning (Ainley & Ainley, 2011), and is seen as an important predictor of children's future steps in science (Maltese & Tai, 2011). In study 3, we showed that children's self-reported inquiry attitude was related to child talk: children with higher inquiry attitudes asked less closed questions and more open-ended *wh*-questions during inquiry. This finding can be considered as a validation of the TOSRA Inquiry Attitude subscale (Fraser, 1981) in the museum context, and shows that children are well able to assess their own inquiry attitude.

Cognitive skills and executive functions play an important role in investigation (Kirschner, Sweller, & Clark, 2006). During investigation, all kinds of cognitive activities are performed, which place a heavy load on children's working memory (Sweller, 1988). For example, these cognitive activities include observing evidence (study 2 and study 3), combining observations of multiple experiments (study 2 and study 3), connecting new observations with prior knowledge to formulate hypotheses and interpret results (study 2), and problem solving (study 3). In study 2, we explored whether children's working memory was related to the quality of families' manipulations and conversations. In study 3, we explored whether children's working memory was related to parent-child interaction, investigation time, and children's solution accuracy. Against our expectations, we did not observe an impact of children's working memory on any of these indicators. One explanation is that the parents adjusted their guidance to the needs and capacities of the children, compensating for the differences in working memory. However, in additional analyzes in study 3 we did not observe a correlation between the child's working memory and parental speech. A second explanation could be that the assessment of children's working memory was less valid. The results of study 2 deviated from those of the standardized Dutch averaged on the digit span task (Kort et al., 2005), which supports this explanation. In this study, we measured children's task performance after their investigations at an open-ended exhibit. Therefore, possibly instead of measuring children's working memory, we measured children's selective focused attention (Diamond, 2013). That is, the low performance on the digit span task could possibly be explained by high working memory capacity children intensively investigating at the exhibit, and consequently being tired when participating in the digit span task. From study 2 we concluded that it is important to measure working memory prior to investigation activities. In study 3, we did assess children's working memory prior to children's investigation of the black box. The absence of an effect of working memory on family learning in study 3, therefore, cannot be explained by tiredness as a result of a previous research task. Besides our focus on the impact of working memory, in study 2, we additionally investigated the impact of children's reasoning capacity. Children's cognitive skills are shown to be related to their scientific reasoning (Davidson, 1996; Miller & Weiss, 1981; Welsh, Pennington, & Groisser, 1991). Therefore, we expected that children's reasoning capacities would impact on families' manipulations and conversations. We showed, indeed, that the reasoning capacity of the oldest children was positively related to the proportion CVS-experiments performed by the families (i.e., manipulations), and their reasoning *content* being scientifically correct or incorrect. For the reasoning *skills* (i.e., formulating hypotheses and interpreting results) we did not observe an impact of children's reasoning capacities. In this study, we measured families' use of formulating hypotheses and interpreting results without assessing whether these were scientifically correct or incorrect. An explanation for the above findings could therefore be found in the existence of multiple processes that are at play in investigation, such as, the performance of inquiry skills on the one hand, and reaching correct understandings of concepts on the other hand (Dunbar and Klahr, 1989; Schauble 1990; Van Schijndel, Jansen, & Raijmakers, 2018a). This study shows the latter to be related to the oldest child's reasoning capacities, as assessed with the WISC subscales. This relation can be explained by children with higher reasoning capacities being able to draw better conclusions during investigating, or possibly having more prior knowledge on the subject.

Gender is related to family learning in the museum, parents interact differently with boys and girls (Crowley et al., 2001b; Luce et al., 2013; Siegel et al., 2007). For example, parents collaborate more with girls than with boys in open-ended activities in a museum context (Siegel et al., 2007). In study 3, we have shown that in parent-child dyads, girls more often manipulate alone than boys. And, contrary to Siegel et al. (2007), we have shown that parents more often manipulate together with boys than with girls. This contrasting result demonstrates the context- and task-specific relation between children's gender and parent–child interactions.

Parent characteristics. Children's learning through investigation benefits from parents' accompaniment (Crowley et al., 2001a ; Gleason and Schauble, 1999). Parent characteristics and parent-child interaction in the museum have shown to be related (e.g., Nadelson, 2013; Siegel et al., 2007; Tare, French, Frazier, Diamond, & Evans, 2011). For example, parental pre-knowledge was demonstrated to be related to parent–child conversation and parental guidance style (Eberbach & Crowley, 2017). Differences in parental guidance style, however, could possibly be explained by other parent characteristics than pre-knowledge (e.g., parents' attitude toward learning; Ricco & Rodriguez, 2006; Sigel, 1998; Sigel and McGillicuddy-De Lisi, 2002). This is what we further looked into in study 3. We demonstrated an effect of parental pre-knowledge on parental guidance style, parent-child conversation, and children's learning from inquiry. In addition, we demonstrated an interaction effect of parental pre-knowledge and gender on manipulations: compared to children of mother-child dyads, children of father-child dyads more often manipulated alone when the parent had pre-knowledge. Against our expectation we did not observe main effects of parents' educational level (Szechter & Carey, 2009), attitude towards science (Tare et al., 2011), and gender (Benjamin et al., 2010; Brown, 1995; Nadelson, 2013; Van Schijndel & Raijmakers, 2016) on family learning in study 3. Similarly, in study 2, parent characteristics were less strongly related to family learning than we had expected. Only parents' educational level moderately impacted on families' conversations: families with higher educated parents more often spoke critically about the reliability of performed experiments.

Study limitations and directions for future research. A challenge we encountered in these studies was the selection of questionnaires for measuring attitude-related characteristics in the museum context. For example, to assess children's attitude towards science we used questionnaires for primary (VTB, Dutch science and technology attitude instrument for primary school pupils, Walma van der Molen, Wiegerinck, & Rohaan, 2007) and secondary (TOSRA, Test of science related attitudes among secondary school students, Fraser 1981) education. On the one hand, the VTB subscale Science enjoyment, an informative measure in the school context, seemed to be somewhat less informative in the museum context: most of the participating children (study 2 and study 3) reported a positive attitude towards science. The TOSRA subscale Inquiry attitude, on the other hand, proved to be suitable for measuring children's self-reported inquiry attitude (study 3). Finding suitable and reliable questionnaires for measuring parental guidance styles in the informal context posed an even bigger challenge (study 2 and study 3). Existing clinical questionnaires on parenting styles proved unsuitable for the museum context upon inspection of the questions (Robinson, Mandelco, Olsen, & Hart, 2001). We finally selected How Children Learn Inventory, measuring parents' beliefs about the value of children's discovery learning and learning by direct instruction (Ricco & Rodriguez, 2006). This scale did include relevant questions, though the psychometric characteristics of the scale were not investigated in a museum population. For future research, it would be useful to develop parental questionnaires on topics such as beliefs on how children learn and how parents can optimally guide children's learning in informal contexts, and on parent's science-related attitudes and interests. A second limitation in measuring individual characteristics is that administering cognitive tasks in an informal context is a challenging undertaking. Families visit museums with an agenda that is more geared towards play, investigation, and enjoyment in a social context (Allen, 2004; Falk, & Dierking, 2000), and less towards individual performance of standardized, school-like tasks. In science museum NEMO, most visitor research therefore maximally takes half an hour. In the current research, in order not to overload parents, we did not include questions about cultural diversity or social economic status. Also, we did not systematically ask parents and children on how they experienced the guidance by museum educators and on how they experienced the parent receiving prior knowledge on the exhibit, while the child was not. However, from a participatory point of view, it would be interesting to do so in future research.

5.2.4 Implications for museum practice.

Below we will discuss the implications of the findings for the museum practice, as well as for the formal science education practice.

Children's knowledge representations of natural phenomena. The insight, from study 1, that children can have multiple knowledge representations of buoyancy depending on context (e.g., indistinctive versus exemplar objects), and on task (e.g., predictions versus explanations) offers interesting starting points for science learning in the informal and formal context.

Designing learning materials. The finding that children's knowledge representation of buoyancy depends on context can be used in the designing of learning materials. For example, this insight can be used in the design of an interactive museum exhibit to engage families' investigation of the phenomenon of buoyancy, or in the selection of learning materials allowing pupils to investigate buoyancy in primary school. Depending on the intended learning experience (e.g., investigating versus knowledge acquisition) well-considered choices can be made in the type of floaters and sinkers (e.g., indistinctive versus exemplar objects) that are offered to the families or pupils, respectively. For example, these results suggest that when aiming to stimulate the investigation of causal relationships between variables and observations, one could select more indistinctive objects as learning materials. We have investigated this in a follow-up study (Van Schaik et al., 2020) and found that exploration with systematically-varied cubes can help children in using more advanced strategies (better integration of mass and volume) in predicting buoyancy.

Designing learning activities. The insight that children's knowledge representations of buoyancy depends on the type of questions asked (to predict or to explain) can be relevant for designing learning activities, such as a family workshop in the museum or a lesson sequel for primary school pupils. We showed that children's predictions of buoyancy were more advanced than their explanations: in their prediction they more frequently integrated mass and volume, while their explanations were more mass-based. These conflicting knowledge representations that result from the type of question asked (predict versus explain) can be an interesting starting point for children's investigation of buoyancy. Research into science learning shows that conflicting evidence can encourage children to actively investigate (Bonawitz, Van Schijndel, Friel, & Schulz, 2012; Van Schijndel, Visser, Van Bers, and Raijmakers, 2015). We applied this idea of making participants aware of their pre-knowledge discrepancies in the award winning workshop 'Talking about science' that was developed for a European project aiming to engage family learning (FEAST, Facilitating Engagement of Adults in Science and Technology, 2007; Scientix Resource Award 2011). In the workshop we observed examples of high involvement of parents and children during buoyancy investigation, and discrepancies between predictions and explanations did not only occur in children but also in parents. For future studies, it would be interesting to systematically investigate the impact of pre-knowledge conflicts on family investigation learning in an informal context.

Concept learning in the museum. In this dissertation we are interested in how people learn from and about science within an informal learning context. In study 2, we showed that families' learning through investigation in the museum can be meaningful, both in terms of what families do (manipulations), and what they say (conversations). We also have shown that families' conversations contain misconceptions about the phenomenon investigated, and that guidance strategies by museum educators can contribute positively to families' concept learning. In study 2, families' concept learning of object movement lies in the fact that with museum educator guidance families less often make incorrect remarks about object movement (mass determines the rolling speed), but they do not necessarily formulate a new, more advanced concept of object movement (mass distribution determines the rolling speed). However, questioning one's own misconception is a first step in the overall process of concept learning, and a genuine conceptual change is a slow process (Carey, 2009), which is important for the museum practice to realize when evaluating impact. It is to expect that families only start doubting their misconceptions after having investigated at an exhibit, as we have seen in study 2 with object movement, instead of accepting a scientifically correct concept.

Guidance strategies by museum educators. The fact that describing evidence and giving explanations are both effective guidance strategies for enhancing family learning during investigation is a promising finding for the museum practice. Firstly, these minimal guidance strategies seem less complex to apply than scaffolding, and secondly the describing evidence guiding strategy seems in line with the informal character of museum learning (see also 3.4.5 minimal guidance strategies practice and 5.2.2 scientific relevance). Follow-up research will have to show whether these strategies are also effective at other exhibits, whether they can be effectively taught to and implemented by educators, and whether they can be applied with all families. Within the programs that NEMO Science Museum runs, we have had some good initial experiences with implementing these guidance strategies in training for informal and formal educators. We implemented the strategies in a basic training (Interaction: Educator - Visitor - Exhibit, 2017) and an exhibition manual (Handleiding V4 Humania, 2019) for museum educators, and in a teacher-training of an inquiry learning in primary education method (Maakkunde, www.maakkunde.nl, 2020). We will explain in more detail the training for museum educators. After being introduced to three minimal guidance strategies (including asking open-ended questions), the educators in this training were encouraged to formulate short sentences following the guiding strategies, for six different exhibits. To give the educators something to hold on to, we introduced three caricatural characters that represented the strategies in a teasing way: a sports reporter describing evidence, a know-it-all giving explanations, and a quizmaster asking open-ended questions. In particular for the describing evidence strategy, this proved to be useful for the educators since that guiding strategy was rather unknown to them. After that, museum educators practiced each guidance strategy separately, on the museum floor, in order to experience the effects of the different strategies in interaction with the visitors. We noticed that the implementation of the strategies at times was challenging for the museum educators, especially during the assignment in which we asked them to come up with example sentences themselves. For example, informal observations during the training showed that in describing evidence sometimes too obvious observations were reported and in giving explanations the examples were often too detailed and information dense. Our experience is that, by discussing these examples within the group of educators, by giving educators sufficient opportunity to gain experience in applying the strategies in practice, and by generating examples for more exhibits (e.g. in exhibition manuals) educators are becoming more and more familiar with the strategies.

In addition to informal and formal educators, we also see a potential for informing families visiting the museum. During a one-off parent-child workshop about guiding children's investigation (National Science Weekend-event, 2014, prior to study 2), we prepared three workstations where children could do an experiment together with a science practitioner. At each workstation the practitioner supported the child with a different guidance strategy. Above the workstations large poster boards introduced the guidance strategies in a caricatural way (sports reporter, know-it-all and quizmaster). During the experiment parents were asked to observe the practitioner-child interaction. In informal observations, the practitioners noticed parents' interest in topics such as how children learn and guidance strategies to support inquiry learning. Parents were also interested in reflecting on their own learning process. The poster board characters were a reason for children to reflect on the activity afterwards, and to discuss how they would like to be supported during investigation. We didn't investigate these conversations any further, but we are interested in studying this in a more systematic way in the future and to include learning in the museum more often as a subject matter in museum programs.

Person characteristics. The findings with regard to the impact of person characteristics on family learning and children's knowledge representations could be of interest for museum professionals in making informed choices in exhibition design or audience guidance in relation to desired objectives. When designing a museum exhibition, choices are made that relate to the objectives, subject matter and intended audience of the exhibition, in addition to those that arise from the museum's mission and vision, and that relate to limitations such as technical feasibility, safety, accessibility, cost and time (McKenna-Cress & Kamien, 2013). These choices are preceded by questions such as 'What learning experience are we aiming for?', 'Which phenomena will we present?' and 'What audience age-range do we have in mind?'. During the exhibition's concept development phase, the subject matter is translated in such a way that it fits in with the experience of the intended audience. Relevant questions to consider are, for example, "What concepts are underlying the phenomenon we're presenting?" and "What is the audience's knowledge level of these concepts?".

During concept development, museum practice can benefit from insights from behavioral research. For example, the finding that in 4- to 12-year-old children's solution strategies in predicting buoyancy is age-related, while children's explanations do not show a clear developmental pattern (study 1). And the finding that parental pre-knowledge relates to parental guidance strategy (study 3, see also 4.4.4). These insights show that the difficulty level of an exhibit not only can have consequences for suitability for a certain age level but can also have an effect on the parent-child interaction.

Also, the finding from study 2 that families' manipulations (CVS-experiments) and reasoning *content* (scientifically correct or incorrect) is related to the oldest children's reasoning capacity can be informative. The museum can respond to these differences in children's reasoning capacities through museum educator guidance or exhibition design. For example, by applying multiple levels of difficulty in an exhibit (layering) or by designing open-ended exhibits that are inviting to explore in a family context (see e.g., Dritsas, et al., 1998). Museums can also choose to design exhibits in such a way that the available material automatically leads to CVS experiments (If we take the exhibit from study 2 as an example, this could mean that a limited amount of only two cylinders would be available for investigation, instead of multiple cylinders). However, this would mean that the open ended character of the exhibit would be lost. And it is precisely this variety of possibilities that makes experimenting interesting. For example, it can offer families the opportunity to have meta-discussions about reliability, something we observed in study 2 in families with higher educated parents. Meta-reflection on reliable experimentation is a subject that is rarely discussed in museums by families, even though it is a very topical and relevant subject.

5.3 CONCLUSION

This dissertation is an example of behavioral research in the museum aiming for a better understanding of how families learn from and about science and technology in an informal learning context. As a result of three empirical studies we have learned that children have different knowledge representations of buoyancy, that museum educator guidance strategies impact the conclusions families draw from investigation and that parental pre-knowledge impacts parent's guidance behavior during investigation. These findings can be informative both for fundamental science and for museum practice. With a better understanding of how people learn through investigation, museum professionals can better reflect on how to create informal learning experiences and what they want to achieve with an exhibition. In this way, evidence informed practice can contribute to in-depth museum learning experiences.