COLLABORATIVE SCIENTIFIC REASONING:

HOW PARENTS SUPPORT DEVELOPMENT AND FACILITATE TRANSFER OF A SCIENTIFIC-REASONING STRATEGY

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Thus study was designed to explore how children learn about a scientific-reasoning strategy while engaged in parent-child activity, and specifically to answer two research questions: 1) Can children learn and transfer a scientific reasoning strategy when provided training situated within parent-child activity? and 2) How do parents support young children's learning and transfer of a scientific reasoning strategy? Thirty parent-child dyads with younger (5- to 6-years-old) and older (7- to 8-years-old) children were recruited to engage in shared scientific-reasoning activities in which they were provided training in the Control of Variables Strategy (CVS): a strategy for designing unconfounded experiments and interpreting the experimental outcome. Families were provided opportunities to apply and transfer their learning of the strategy while exploring materials in two domains in two sessions spaced one month apart.

When provided training situated within parent-child activity, 5- to 8-year-old children demonstrated that they could learn to use CVS. Although both older and younger children were able to learn the strategy, age-related differences were detected in children's transfer abilities.

While older children continued to improve in their use of CVS at the second session, younger children's performance decreased. In answer to Research Question 2, this study illuminated ways that parents and young children engage in scientific activity and build on subsequent related activity. To support children's engagement, parents varied their support in the design and execution of experiments and they engaged in conversations that supported planning and evaluating activity. Parents reminded children of the strategy and redirected activity to support the generation and evaluation of interpretable evidence. We observed that parents sometimes explicitly reminded children of prior shared activity; these parents were more likely to have children who later became the most reliable users of CVS. Further research is needed, however, to establish causal links between specific types of parent support and patterns of parent-child activity and resultant child learning and transfer.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Children as Scientists

Children spend much of their early years learning about and exploring novel things. They figure out how new toys or computer games work and explore new places, such as playgrounds and museums. Not only do they acquire knowledge about specific things in the world, they learn about exploring as well. Many aspects of these activities can be viewed through a lens of scientific reasoning, as they provide children with opportunities to form and test hypotheses and generate and evaluate evidence. Much research has been conducted on the development of scientific thinking, and children have often been characterized as born scientists who explain and predict phenomena on the basis of intuitive theories. Young children are curious and enthusiastic, instinctively seeking out evidence, noticing patterns, drawing conclusions and building theories (Brewer & Samarapungavan, 1991; Simon, 2001; Vosniadou & Brewer, 1992). Conversely, many studies have elaborated ways in which children are not good experimental scientists. Children, and even sometimes adults, have difficulty designing informative experiments, ignore inconsistent data, fluctuate in their beliefs, are inappropriately influenced by prior beliefs, and do not realize when their theories are incomplete or flawed (Dunbar & Klahr, 1989; Klahr & Dunbar, 1988; Kuhn, Amsel, & O'Loughlin, 1988; Schauble, 1996).

Early explorations of scientific reasoning often studied isolated component processes (e.g., hypothesis testing, experimentation skills, or evidence evaluation), whereas more recent research on the development of scientific reasoning skills has focused on self-directed experimentation (Zimmerman, 2000). Although recent research often integrates the component processes involved, these scientific activities are still primarily studied in isolation from the everyday settings and social contexts in which they develop and are practiced (Chinn & Malhotra, 2001). Much of what is currently known about the development of scientific reasoning was discovered in the laboratory context with individual children performing tasks designed by the researcher. This research informs us about what children can do in controlled and contrived settings, however, yet to be discovered is whether or how these findings generalize to children's experience in the social world.

Why Study Parent-child Activity?

Prior to encountering formal science instruction in school, children experience science with parents at home, in their backyards, in parks and in museums, among other places (Callanan & Jipson, 2001; Korpan, Bisanz, Bisanz, Boehme, & Lynch, 1997). They form early ideas about what science is and about how one does science. They collect information, test hypotheses, and revise theories, often collaborating with or being supported by their parents (Crowley & Callanan, 1998). Participation alongside family members in shared, valued activity helps children learn about and practice new skills in supportive and meaningful contexts. We are interested in studying these early scientific experiences, not only to better understand what children know about scientific content and processes, but also to better understand how they come to know it. Although parent-child learning has been studied in home, everyday, and laboratory contexts (e.g., Callanan & Oakes, 1992; Gelman, Coley, Rosengren, Hartman, & Pappas, 1998), little is known about how specific patterns of parent-child activity impact the development of children's scientific thinking.

To better understand the development and nature of early scientific thinking, two relatively disparate literatures – children's scientific thinking and parent-child activity – will be integrated to suggest the importance of an additional area of study—the *in vivo* development of scientific thinking. By exploring parent-child activity, it is possible to observe how families engage in activity and what various roles family members play. We can describe how parents model behavior, shape children's scientific experiences, and talk to them about scientific content.

We label this type of parent-child learning as "in vivo" following Klahr's (2000; Klahr & Simon, 1999) distinction of overlapping empirical investigation areas of science. Most extant research on the development of scientific reasoning, conducted in the psychology laboratory, can primarily be categorized as simulated science, an *"in vitro"* approach. The *"in vivo"* approach often studies "real" science, observing adult professional scientists engaged in their day-to-day activities (e.g., Dunbar, 1995). This *in vivo* approach offers benefits of studying authentic scientific practice. However, authenticity comes at a price. It is necessary for the researcher to have a deep understanding of the scientific content being studied as well as for the scientists to allow the psychologist into the laboratory. Thus, it is both difficult and time consuming. The *in vitro* approach, although less authentic, offers many advantages: particular participants can be selected, prior knowledge and the "state of nature" can be controlled, and both successes and failures may be observed repeatedly. However, it is believed that even simple laboratory studies do tap into the everyday thinking and reasoning processes that are fundamental components of scientific thinking (Klahr, 1994, 2000). The objective of this review and the proposed study is to suggest the importance of an additional area of scientific investigation that takes advantage of both of these approaches. The study of in vivo development of scientific reasoning would thus turn to children's engagement in shared scientific activity with parents to learn more about the processes of development.

Studies of parent-child activity can situate themselves in various locations in the spectrum from the spontaneous in everyday settings to the controlled in the laboratory setting. In fact, it is probably informative and important to study aspects of parent-child activity from multiple places in the continuum. The study described here falls somewhere in the middle, as it explores parent-child activity in both self-directed and controlled settings.

Several issues that arise from the synthesis of the development of scientific reasoning and the parent-child learning literatures will be discussed at the end of the Literature Review. An outline of these four Synthesis Points will first be presented here so that they might help situate and guide the readers' interpretation of the literature in the next chapter. The Synthesis Points elaborate characteristics of parents, children, and their shared experiences that might shape the development of scientific thinking and the study of parent-child scientific activity.

1) During shared scientific thinking, parents and children work together to negotiate the goals of the activity.
2) Parent-child scientific thinking is an example of distributed cognition, with each member playing a unique role.
3) Through joint activity, children and parents co-develop systems of shared knowledge about science, including both content and processes.
4) Joint scientific thinking can be hindered by problems of communication. First, parents are often unaware that aspects of scientific thinking that are self-evident for them can be difficult for their children. Second, young children often know more than they are able to explicitly talk about with their parents.

Parent-child everyday and informal learning activity is therefore an important context in which to explore the processes of early development. Parents have many opportunities to support children's development, and may do so by building on children's developing interests and by referencing shared prior experiences. Through their experiences together, parents and children develop bodies of shared content knowledge, but perhaps even more important than the content learning that takes place is that children learn about learning, making connections, and about ways of gathering information in the world. Additionally, the complex systems of knowledge that parents and children develop and share provide them with a platform for more sophisticated conversation and reasoning than would have otherwise been possible. Furthermore, through these types of activities, parents extend their knowledge of their children as learners. We want to learn more about the mechanisms involved in parent-child co-construction of knowledge and how day-to-day interactions shape development over time. In the first part of the study, parents and children will be taught a scientific reasoning strategy in order to explore how parents support children's learning during scientific reasoning. The second part will be conducted four weeks later and will observe parent-child activity as they explore a related task. An important way of learning is relating new information to what is already known, thus, our second focus is on learning more about how parents facilitate transfer of prior knowledge to new situations.

Research Questions

The general goal of this study is to learn more about the development of scientific reasoning by exploring one context in which much of children's early learning and development often occurs—parent-child activity. More specifically, the study has been designed to investigate ways that parents support children's learning, both during initial learning and then during subsequent related activities. This research is thus guided by the following research questions:

1) Can children learn and transfer a scientific reasoning strategy when provided training situated within parent-child activity?
2) How do parents support young children's learning and transfer of a scientific reasoning strategy? Are there age-related differences in the kinds and levels of support that parents provide?

To address the above research questions, this study will consist of two sessions conducted four weeks apart in order to explore ways that parents support children's learning of new information as well as facilitate transfer during a second related activity. In each Session, there will be a pretest, an exploration of the task, a collaborative posttest, and an individual posttest. This study will employ tasks used in previous research investigating children's learning of a domain-general strategy referred to as the Control of Variables Strategy (CVS) (e.g., Chen & Klahr, 1999; Triona & Klahr, 2003). In procedural terms, this strategy is discussed as a method for designing experiments in which a single contrast is made between experimental conditions. Beyond the design of experiments, an understanding of CVS includes the ability to distinguish between confounded and unconfounded experiments. Described in logical terms as well, the strategy includes the ability to make appropriate inferences from the outcome of unconfounded experiments, as well as the ability to understand that confounded experiments produce uninterpretable results. Given that designing good experiments and interpreting the outcomes are fundamental scientific reasoning activities and important skills for children to learn, and that elementary schoolchildren rarely use CVS spontaneously (Chen & Klahr, 1999), it is important to understand more about how parents can support learning and transfer.

Before focusing on patterns of parent-child activity, a primary question of this study asks whether young children can in fact learn CVS. In measuring what children know prior to engaging in the activity and then, following training, how they perform both in collaboration with parents and on their own, I will be able to measure changes in understanding and use of CVS as well as the understanding of the variables in each of the tasks. As discussed by Chen & Klahr (1999), the measures in various phases of the study differ on a range of factors, requiring a range of near and far transfer. A taxonomy for far transfer will be used to discuss patterns of learning in the present study to better describe how each activity or measure differs on several context dimensions from the training (Barnett & Ceci, 2002). It is hypothesized that the more dimensions on which the task differs from the learning context, the more difficult it will be for children to transfer their learning.

The second Research Question focuses on exploring how parents and children engage in joint scientific-reasoning activities to better understand how parents support children's learning and transfer. Much research has been done independently exploring the scientific reasoning processes of children working solo and also on parent-child reasoning activities. However, not much work has investigated how parent-child activity impacts early scientific reasoning activity. Recent descriptive research on parent-child activity has revealed that parents sometimes ask questions, give directions, direct attention, or explain (Crowley, Callanan, Jipson et al., 2001; Crowley & Galco, 2001), and furthermore, has demonstrated the immediate impact of parent explanation following the exploration of a museum exhibit (Fender & Crowley, 2004, under review). The present study extends such work to explore patterns of parent support of young children's strategy and content learning. We predict that parents who support experimentation by encouraging active child participation or by discussing strategies for designing experiments and interpreting outcomes will have higher initial posttest scores.

The second aspect of Research Question 2 focuses specifically on the issue of transfer. Although parents may employ strategies to support children's learning as information is first encountered in the initial learning phase, they may employ different types of support to remind children of prior knowledge at the time of transfer. Parents and children in this study engaged in a scientific reasoning task and later explored a different task with deep conceptual similarity (the CVS strategy may be used to explore causal status of the different variables in both tasks). We predict that children whose parents employ strategies for activating prior strategy knowledge or remind children of prior shared activity will, following exploration of a task in a second domain, have similar or possibly greater use of the strategy in the second session. Additionally, parents who help children recall key aspects of prior activity during the subsequent related task may then be better equipped to transfer the strategy while reasoning on their own.

The final aspect of Research Question 2 concerns age-related differences. Are there age-related differences in the kinds and level of support that parents provide? As will be further described in the discussion of the Synthesis Points, problems of communication may impact joint scientific reasoning. Because younger children generally appear less competent on the surface, it is possible that parents may be more sensitive to providing assistance during joint reasoning. With older children, then, because they demonstrate more competency, parents may miss opportunities to support the reasoning and the making of inferences (Gleason & Schauble, 2000). Additionally, if parents' perception of children's abilities is lower, this may impact how they establish goals for the activity and share responsibility with children. Therefore, the data will be explored for age-related differences in parent-child activity.

Before discussing the particular details involved in the design of the proposed study, it is important to review what is known about the development of scientific reasoning skills and parent-child learning. In terms of scientific reasoning, the primary focus will be on children's reasoning abilities; however, it will also be important to review areas in which adults demonstrate particular difficulty on scientific reasoning tasks. This will enable us to better understand the areas in which parents could most easily assist children's reasoning. In exploring the answer to Research Question 1, the review of this literature will help us better understand and interpret children's performance in the present study. Second, studies of parent-child activity will also be reviewed to explore methods that parents employ to support young children during general reasoning activities. Finally, the research on parent-child everyday and informal scientific reasoning will be reviewed. The review of the parent-child learning literature will help us address Research Question 2 by better informing us about the ways parents have been observed engaging in reasoning activities with children and supporting their learning. Finally, the literature review will conclude with a discussion of the Synthesis Points that integrates what we learned from these literatures about issues in studying and understanding parent-child shared scientific reasoning activity.

CHAPTER 2

LITERATURE REVIEW

Prior to discussing the design of the study and exploring answers to the research questions, several literatures will be reviewed. First, in order to address Research Question 1 – Can young children learn and transfer a scientific reasoning strategy when provided training situated within parent-child activity? – the large body of work on the development of scientific reasoning will be reviewed. This literature will inform us of what is currently known about children's abilities on a variety of scientific reasoning tasks.

Development of Scientific Reasoning

Scientific reasoning can be characterized as a specialized form of problem solving (Simon & Lea, 1974). In information processing terms, Newell and Simon (1972) talk about problem solving as being made up of an initial state, set of operators that allow movement from one state to another, and a goal state or solution to the problem. Two essential problem-solving activities in scientific reasoning are (a) designing and executing unconfounded experiments and (b) evaluating evidence to make inferences from experimental outcomes (Chen & Klahr, 1999). Early scientific thinking research employed tasks that typically focused on the investigation on only one of these particular scientific reasoning components (Zimmerman, 2000). These studies of isolated components simplified the scientific reasoning process for study participants, as well as the study of the scientific reasoning for experimenters. A study of how people evaluate evidence typically would, for example, provide participants with the evidence to evaluate, rather than engaging participants in the design and execution of experiments in order to generate that evidence. However, more recent research has focused on integrated components of scientific reasoning with study participants typically engaged in self-directed experimentation. An important feature of more recent research is that it integrates both concepts and strategies for a more complete picture of the scientific reasoning process (Dunbar & Klahr, 1989; Klahr & Dunbar, 1988).

The review of the development of scientific thinking literature will be primarily organized by dividing research into that which studied isolated components and that which explored integrated components. The first section will examine what we know about how children and adults think about experimentation and how they engage in evidence evaluation, with the second main section exploring how participants integrate components of scientific thinking during self-directed experimentation.

Studies of Scientific Reasoning Components

Experimentation

Experiments generate information that can serve as evidence and that can be related to hypotheses, and therefore serve an important function in gathering information about the world (Zimmerman, 2000). Some research on experimentation skills has focused on peoples' ability to produce complete factorial combinations of variables. This skill is important because it enables people to produce a complete set of possible evidence, which allows for the causes, effects, and interactions to be observed. Another focus of experimentation research has been on peoples' abilities to isolate variables and produce unconfounded experiments. Isolating one variable is accomplished by holding all of the other variables constant and only changing the levels of one variable of interest. Being able to isolate a particular variable of interest enables valid inferences to be made from the evidence generated. When confounded experiments are conducted –when a variable has not been isolated –the evidence is not interpretable and inferences can not be made about the causal status of the variables. If differences or effects are observed following a confounded experiment, it is not possible to attribute those differences to a particular variable.

The function of experimentation differs depending on the state of a person's prior knowledge; experimentation can function either to discover or to confirm hypotheses (Klahr & Dunbar, 1988). People engage in discovery experimentation to generate observations in order to induce hypotheses that account for patterns of data. When no hypothesis or theory is available, experimentation provides information that can be used to discover or form a hypothesis. Conversely, in confirmation/verification experimentation, when one possesses relevant prior knowledge and perhaps a theory about the situation, one tests the tenability of the existing hypothesis under consideration. People set out to find evidence that could confirm (or disconfirm) a theory they already are considering.

Early research on experimentation skills minimized the role of prior knowledge and investigated participants' discovery experimentation skills—how well they conducted experiments without prior theories of how the system functioned. By not allowing participants to discover the rule that controlled the operation of the system until the entire factorial space was explored, Siegler and Liebert (1975) studied participants' ability to produce complete factorial combinations. The 10- and 13-year-old participants who were provided with both instructional support and opportunities to complete practice problems were more likely to produce a complete factorial array. The older group of children, who were not provided instruction or the opportunity to engage in practice tasks, was also more likely to be able to produce a complete array, whereas the 10-year-old children needed both types of support to be successful. This study revealed record keeping as a predictor of success; although the 10-year-olds were significantly less likely to keep records, those that did so were more likely to produce the complete factorial array. These age-related differences are thought to be related to advances in metacognitive awareness. In addition to metacognitive advances, skill in systematic rule use emerged as an important precursor for competence in experimentation with multiple variables (Kuhn & Phelps, 1982; Siegler & Liebert, 1975; Zimmerman, 2000).

Rather than focusing on participants' ability to produce experiments for all the levels of every variable, the majority of research on experimentation skills examines participants' ability to isolate or control variables to produce unconfounded experiments. Because this research typically either provides participants with a theory or situates the experimentation in everyday situations, this type of research explores subjects' confirmation experimentation skills—how well they conduct experiments when prior theories are available. Tschirgi (1980) hypothesized that experimentation skills develop as a result of everyday experiences in which people try to avoid negative outcomes and replicate positive outcomes. Participants in this study therefore were asked to reason about stories with content with which even young children would be familiar (e.g., baking a cake, feeding a cat, going fishing). For example, a character whose regular cake-baking ingredients (e.g., white flour, sugar, and butter) were not available baked a cake with wheat flour, honey, and margarine. Because the cake turned out so well, the character developed a hypothesis that the honey caused the cake to be great and that the types of flour and shortening did not matter. This study examined the performance of 7-, 9-, 11-year-olds and college students, looking specifically at peoples' ability to manipulate variables to produce a conclusive test. Participants were asked to choose the best experiment to prove the story character's hypothesis from the following three types of choices: a Vary One Thing At a Time (VOTAT) choice, a Hold One Thing At a Time (HOTAT) choice, and a Change All (CA) choice. The VOTAT strategy appropriately varied only the test variable, whereas HOTAT and CA strategies varied more than one variable, thus producing confounded experiments.

The main finding of this study was that when children and adults were asked to reason about experiments in familiar, everyday events, they indeed proved to be sensitive to the nature of the outcome of the event. When faced with a bad result, participants searched for the one thing they could change in order to get rid of the bad result; this appeared to be a systematic search of the variables where participants changed the bad variable and held the others constant (VOTAT strategy). However, when there was a positive outcome, participants focused on the one thing they could keep to maintain the good result (HOTAT strategy); they preferred a testing strategy in which they held the good variable and changed the one or more of the other variables to maintain the positive result. If the character in the story believed that using honey as the sweetener, for example, produced a good cake, participants were unlikely to conduct an experiment employing a VOTAT strategy in which they would change the level of the test variable (sweetener). Conducting an unconfounded experiment of the test variable would involve intentionally trying to produce a bad cake. Thus, participants appeared to be more concerned with the functional effects of their manipulations and their goal seemed to be producing or maintaining positive effects, rather than providing conclusive tests of the effect of a variable.

The pattern of responses for the youngest children was similar to older children's and adults', however they were the most likely to, even in the case of eliminating a negative effect, to vary more than one thing at a time. In the negative result situation, adults and 11-year-olds were able to appreciate the appropriateness of the VOTAT strategy over the CA strategy, even though the “bad” variable is eliminated in both cases. However, the 7- and 9-year-olds were much less able to discriminate the appropriateness of the VOTAT strategy from the CA strategy. The authors proposed that the younger children might have realized that the bad variable needed to be eliminated in order to remove the bad results, but they might focus on solely on this rather than working to establish particular variables as being causal.

These early experimentation studies focused on participants’ abilities to reproduce effects. Moving beyond this to examine whether young children appreciate the difference between testing a hypothesis and reproducing an effect, Sodian, Zaitchek, and Carey (1991) explored 6- and 7-year-old children’s abilities to both recognize and produce conclusive experiments situated in everyday contexts. This study presented children with a mouse and cheese story with “feed” and “find out” conditions. In the condition where participants wanted to be sure to feed the mouse, it would be necessary to use a mouse hole that was big enough for either a big or small mouse, whereas in the “find out” condition, participants should choose a small mouse hole in order to determine whether the mouse was big or small. In the forced-choice version of the study, 50% and 86% of 6- and 7-year-olds, respectively, could differentiate between conclusive and inconclusive tests. They were able to provide the reasoning behind their choice, demonstrating that they were not simply trying to reproduce a desirable result. In a follow-up study, where children were asked to devise spontaneous solutions, about one quarter of children as young as 6-years-old were able to generate conclusive tests of hypotheses.

These studies demonstrated that young elementary-school children could successfully reason about experimentation in everyday reasoning situations. However, when engaged in scientific discovery tasks (e.g., Kuhn, Garcia-Mila, Zohar, & Andersen, 1995), even older elementary school children have demonstrated a weak understanding of how to actually produce unconfounded experiments. Sometimes referred to as the Control of Variables Strategy (CVS), the skills of producing unconfounded experiments and making inferences based on the results are essential in scientific reasoning. Because it is rare that young children spontaneously use CVS during experimentation, Chen and Klahr (1999) explored whether 7- to 10-year-olds could be taught through direct instruction and probing questions to use CVS in designing experiments. Overall, both older and younger children benefited from instruction and were able to understand and learn CVS when designing simple experiments. Not only were 9- and 10-year-old children able to learn the strategy, but also their use of the strategy resulted in increases in knowledge. In other words, instruction was able to increase children's ability to design unconfounded experiments, which in turn resulted in improved understanding of the effects of the variables involved.

In sum, research that investigated experimentation skills has shown that children as young as 6- or 7-years-old understand aspects of experimentation. When provided opportunities to reason scientifically about everyday situations with familiar content, children understood the difference between testing a hypothesis and reproducing an effect; they could recognize and sometimes even generate simple tests of hypotheses. When working to eliminate a negative experimental result with multiple variables, 7-year-old children sometimes successfully recognized unconfounded experiments. Conversely, when reasoning about a situation in which they wanted to maintain positive results, children and even adults demonstrated difficulty in rejecting strategies in which they varied more than one variable. However, instruction about a strategy for controlling variables during experimentation provided the information and support needed for even early elementary school children to be able design unconfounded experiments while engaged in scientific discovery tasks involving multiple variables.

Evidence Evaluation

The ability to review and make inferences from available data is an essential skill in scientific reasoning. Experimentation is an important component of scientific discovery because it generates a set of data to evaluate. However, without appropriate skills for assessing the data produced, even the best experimentation skills would be useless. Kuhn and her colleagues (e.g., Kuhn, 1989; Kuhn et al., 1988) have argued that the set of skills involved in differentiating and coordinating theory and evidence is the defining feature of scientific thinking. Included in this set of competencies would be the ability to articulate a theory, to understand the type of evidence that supports or contradicts a theory, and to justify the selection of one theory among competing theories that propose to explain the same phenomena. Because this is such a complex and important skill, much scientific reasoning research has been conducted to explore aspects of children and adults' evidence evaluation abilities.

To study evidence evaluation skills in isolation from experimentation skills, participants are typically provided with a set of evidence. Without actually conducting experiments, participants do not have access to such indices of causality as the principles of priority (causes precede effects) or temporal contiguity (causes and effects must be contiguous in time and place). However, it is possible to provide participants with a record of the instances that one variable occurred or did not occur with another; much of the research on evidence evaluation skills has provided participants with exactly this type of data: covariation evidence. The principle of covariation states that in a situation with several potential causes, the true cause will be the one that regularly and predictably covaries (or co-occurs) with the effect. Thus, the ability to identify covariates is an effective way to narrow down possible causes of an event during everyday scientific reasoning.

Covariation evidence is sometimes presented to participants in table form. Participants in this situation are asked to consider two variables, a potential “cause” and “effect”, and are presented with information about their co-occurrence. Often this information is represented in a 2 x 2 table (see Table 1), with Cell A representing the number of times the cause and effect co-occurred, Cell B representing the presence of the cause and absence of effect, Cell C representing the absence of the cause but the presence of the effect, and finally Cell D representing the number of instances when both the cause and effect were absent. Participants are asked, given the pattern of covariation, to determine if it is likely that the potential cause actually did cause the effect.

Table 1: Cells in a 2 X 2 contingency table for studies using covariation evidence

	Outcome - "effect"	
Antecedent - "cause"	Present	Absent
Present	A	B
Absent	C	D

To study children’s strategies for evaluating evidence and their ability to make judgments based on patterns of covariation data, Shaklee and Paszek (1985) presented 7- to 9-year-olds with 2 x 2 tables of data. Children were asked to make judgments about which things may or may not go together and researchers adapted this task for younger children by putting small pictures in the covariation tables rather than numbers (i.e., in a table about whether plant food was responsible for healthy plants, the table included the little pictures of healthy or sick plants and pictures of food or no food). This study identified four problem strategy types that participants could use to evaluate covariation evidence: (a) observe Cell A, the frequency of co-occurrence, which was the simplest strategy; (b) compare Cell A vs. B, where one compares the number of times the effect occurs with cause/covariate as compared to number of times it does not occur with the cause present; (c) sum of diagonals strategy, comparing frequencies of events confirming relationship with events disconfirming it; and (d) the conditional probability strategy, a mathematical comparison. Children were categorized as knowing a strategy if they were accurate on two or more of the three problems that required that particular strategy. Of these possible strategies for evaluating covariation evidence, the A vs. B strategy was most common, as well as generally being the highest level at which most children reasoned (only one child from each group was categorized as using ‘sum of diagonals’ and no children used the conditional probability strategy). By age 9, 70% of children shifted towards a strategy of comparing Cell A with B, while less than 45% of 7- and 8-year-olds were observed using this strategy. These younger children often demonstrated a response bias (e.g., always choosing the first option) or unclassifiable strategy use.

Because the comparative aspect of the task was a source of difficulty for the younger participants, a follow-up experiment explored the impact of varying support on children’s use of the A vs. B strategy for evaluating covariation evidence. Seven-year-old children were placed into one of the following conditions: (a) Control- instructions about the task, (b) Attention only- instructions, plus directing attention to Cells A and B, and, (c) Attention plus more- instructions, plus directing attention to Cells A and B with the question directing them to compare, “Which of these two things happened more?” The Attention plus more group showed significant improvement in use of the trained A vs. B strategy over the Control and Attention only group. These studies together showed that the comparative aspect of evaluating tables of covariation data seemed to be a source of difficulty for 7-year-olds; they did not spontaneously decide to compare information from multiple cells to develop a single judgment. However, they could be successful in the use of the A vs. B strategy when supported by multiple prompts to compare cells.

Rather than focusing on how participants interpreted tables of covariation data, much of the research on evidence evaluation has explored the influence of participants' prior knowledge. For instance, Kuhn et al. (1988) examined how participants reconciled prior beliefs with covariation evidence that either confirmed or conflicted with those beliefs. Following initial interviews to determine participants' beliefs about the causal status of various variables, 11-year-olds, 14-year-olds and adults were provided covariation information regarding type of food eaten (e.g., types of fruit and types of condiments) and whether people got colds. Based on their initial beliefs, four variables were selected so that two were considered causal and two were non-causal for each participant. This allowed for the covariation evidence to confirm one casual and one non-causal theory and to disconfirm one previously believed causal and one non-causal theory. Responses provided were coded as evidence-based if they referred to the data or patterns of covariation, or theory-based if they referenced prior beliefs. Eleven-year-old children were significantly less likely to explicitly refer to evidence when explaining their reasoning than were 14-year-old children and adults. However, by 11-years-old, most children demonstrated some ability to know how evidence bears on theory.

Another aspect of prior theories that could potentially affect evidence evaluation could be the strength with which a person holds a theory. To identify strongly held causal and non-causal theories, Kuhn et al. (1988), presented participants with evidence in two separate interviews held a week apart and asked them to choose the most influential causal and non-causal variables. Including 8-year-old participants, as well as 11- and 14-year-olds and adults as in previous studies, this study revealed that whereas the older groups of participants revealed that their theories were highly stable, only half of the 8-year-old participants demonstrated this. The strength or certainty with which a participant holds the theory was shown to influence how the evidence provided was evaluated. Additionally, nearly all subjects did not create new theories to maintain alignment of theory and evidence. Instead, the participants again reconciled the theories with evidence by ignoring implications of evidence or evaluating it in a biased way. The 8-year-old participants responded similarly to 11-year-olds, however they were even more likely to make theory-based evaluations and demonstrated biased evaluation of evidence.

Kuhn and colleagues' extensive line of work on evidence evaluation skills (Kuhn, 1989, 1993a, 1993b; Kuhn et al., 1988; Kuhn et al., 1995; Kuhn, Schauble, & Garcia-Mila, 1992) revealed three main patterns of behavior (Zimmerman, 2000). First, participants showed a steadily improving developmental trend from middle childhood to adolescence to adulthood, although even adults did not perform as an ideal reasoner (e.g., participants sometimes used prior beliefs rather than available evidence as justifications for their causal judgments). This pattern involved a set of behaviors that participants engaged in to maintain alignment between their theory and the evidence when the two actually were not in alignment. Examples of these behaviors include merging theory and evidence into a single view of "the way things are" and ignoring or distorting evidence that does not support the current theory. The second pattern involved adjusting a theory to fit the evidence. Zimmerman commented that although this could be viewed as perfectly reasonable behavior, it was not in this case because this process seemed to be outside participants' conscious control; they were unaware that they were adjusting their theory. The third pattern involved understanding how covariation patterns relate to causality. When asked to show a pattern of non-covariation evidence, participants instead constructed covariation evidence in the opposite direction of their own causal theory.

Several authors have challenged the work of Kuhn and her colleagues, questioning whether children as old as 8- through 11-years-old could not actually distinguish their beliefs from evidence that could prove or disprove those beliefs (Amsel & Brock, 1996; Koslowski, 1996; Ruffman, Perner, Olson, & Doherty, 1993; Sodian et al., 1991). Because experimentation research has shown how 6- and 7-year-old children could recognize and sometimes even generate simple tests of hypotheses and be taught to use CVS in even more complex scientific reasoning activities, it is important to better understand whether they are able to appreciate the products of their experimentation. Because of the claims that children are unable to understand the hypotheses-evidence relation until between 8- and 12-years-old, other researchers, using various methods, have investigated young children's abilities to reason about hypothesis-evidence relations. For instance, the work of Sodian et al. (1991) showed that children as young as 6- and 7-years-old could select and sometimes generate conclusive tests of hypotheses. As children selected or generated conclusive tests for determining mouse size, they necessarily needed to be able to consider how the potential evidence produced from their test would relate to their hypothesis.

Taking the position that previous work underestimated children's abilities, a series of studies attempted to better assess the age at which children are able to understand how hypotheses can be either supported or contradicted by evidence. Ruffman, Perner, Olson, and Doherty (1993), investigating whether 4- to 7-year-old children could form hypotheses based on covariation evidence, designed studies to demonstrate that children are capable of various hypothesis-evidence related metacognitive skills earlier than previous research indicated. One motivating factor for this study was that earlier work often focused on children's justifications, rather than their understanding. This methodological issue may have contributed to this underestimation of children's understanding, as children's ability to explain their understanding develops later than the actual understanding (Flavell, Miller, & Miller, 1993). To avoid the added complications of interactions with participants' own prior beliefs, these studies employed a "fake-evidence task" methodology and the introduced a third person's perspective (a doll). Subjects were asked to evaluate a causal relationship given the evidence, and to identify, given the condition of the evidence being switched, how someone else (the doll) could draw a false conclusion. This ensured that children were assessing the hypothesis based on evidence and independently of their own beliefs.

These studies demonstrated that children as young as 5-years-old can form causal hypotheses based on covariation data (Ruffman et al., 1993). In study 1, 4- and 5-year-old children were shown the Fake Evidence Task, with a story about which food caused poor teeth. Provided with perfect covariation data, 5-year-olds performed significantly better than chance and better than the 4-year-olds in answering hypothesis-evidence questions. The second study expanded these findings by demonstrating that children understood that evidence did not need perfect for them to draw conclusions. In a third experiment, the researchers investigated whether 6- and 7-year-old children were constructing hypotheses to merely describe the evidence, or if they could use hypotheses to predict future events. They further investigated children's ability to form generalizations from the evidence, and to associate a particular state of the evidence with a particular hypothesis. Children's ability to make the distinction between evidence and hypotheses was once again replicated. Children as young as 6-years-old were able to understand that evidence provides information that could be used to make generalizations (e.g., information that a tennis racquet produced a good serve can help decide which racquet to buy). By 7-years-old, children were able to use a newly formed hypothesis to make predictions (e.g., information that a tennis racquet produced a good serve helps predict whether next serve is likely to be good) (Ruffman et al., 1993).

Because prior beliefs have been shown to influence scientific reasoning processes, some studies have attempted to eliminate the influence of prior beliefs methodologically, as was done by using the fake evidence task in the previous study (Ruffman et al., 1993). However, because prior beliefs are a component of everyday authentic scientific reasoning, other research incorporates them into the research design to better assess how prior beliefs influence participants' evidence evaluation. The research of Amsel and Brock (1996) was motivated by the findings that children and sometimes even adults are inappropriately influenced by their prior beliefs even when asked to evaluate solely on the basis of the data provided to them. This study differs from earlier work on several factors: the task was less cognitively demanding (presented a reduced number of variables than earlier work), causal judgments were assessed separately from justifications, and the instances in each data set were presented all at once, rather than sequentially. Studying a wide age range of participants and their evidence evaluation skills, Amsel and Brock (1996) presented 4 groups of participants (7- to 8-year-olds, 11- to 12-year-olds, non-college adults, college adults) with covariation data about plant growth. Subjects were first interviewed to first determine that they held correct beliefs about the causal and non-causal variables (specifically, that they believed sun was causally related to health of plants and "presence of a charm" was not causally related) and then, in a second interview, were asked to make causal judgments based on the data and provide justification for their judgments.

Regarding causal certainty judgments, both children and adults judged variables as causal when they covaried and non-causal when they did not covary. This replicates previous research (e.g., Koslowski, Okagaki, Lorenz, & Umbach, 1989; Ruffman et al., 1993) that found that adults and children evaluate the same variable as causal or non-causal according covariation data they are provided. There also was an effect based on prior beliefs; subjects were more likely to think the sun was causally related to the health of plants and therefore had higher causal ratings for sun even with non-covariation data. However, the authors report that the college students were the closest to the "ideal reasoner" in that they were least influenced by prior beliefs and were the most likely respond according to the covariation data presented, even when it conflicted with prior beliefs.

Other differences were found in children and adults' evidence evaluation skills, with one large difference found in their justifications for causal judgments. Whereas adults provided evidence-based judgments for the majority of their responses, children made evidence-based justifications for only a minority of their justifications. Second, when the data disconfirmed a prior belief about the variable, children, unlike adults, were likely to make judgments about the variable that were consistent with their prior beliefs. Overall children's reasoning was not as "ideal" as the adults; their judgments were more greatly influenced by prior beliefs and they gave fewer justifications based on evidence. The influence of prior beliefs on children's evidence evaluation may have been detected in this study when not found in previous work partly because of rich task domain knowledge and strength of the beliefs about the variables. This study concludes that the methodology used in evidence evaluation studies can either highlight children's abilities or their biases.

The assumptions, methods, and interpretations of many evidence evaluation studies, and of Kuhn and colleagues specifically, have been questioned because they often assess skills by asking participants to judge causality based solely covariation data (Koslowski, 1996). Doing so may have contributed to a distorted or incomplete understanding of the evidence evaluation abilities of children and adults. Koslowski asserts that it is not necessarily good scientific practice to disregard all prior knowledge and rely only on current covariation data. Additionally, although covariation is a necessary for variables to be causally related, it is not sufficient—covariation does not imply causation. Because the true cause will be the one that regularly and predictably covaries with the effect, identifying covariates is a useful way to narrow down possible causes of an event during everyday scientific reasoning. In authentic scientific reasoning, covariation information is used to help decide which of all possible causes scientists should study as most likely causal. Koslowski's position builds on earlier research that showed that adults and children consider factors beyond covariation in making causal judgments, such as causal mechanism, sample size, and the status of rival alternative accounts (Koslowski & Okagaki, 1986; Koslowski et al., 1989).

In these varied evidence evaluation studies, both adults and children demonstrate some competency in accurately evaluating evidence in everyday and scientific reasoning situations. From the research presented it is clear that both children and adults do not typically evaluate patterns of evidence in a "vacuum" but rather bring with them prior experience and theories. The early work on evidence evaluation (e.g., Kuhn et al., 1988) focused on participants' abilities to ignore all information except for that that was presented to them (typically in covariation tables), whereas more recent work (e.g., Amsel & Brock, 1996; Koslowski, 1996) argued that it is more scientifically legitimate to not ignore one's prior knowledge or theories and use that information along with covariation data to evaluate evidence. Because of these disagreements in the assumptions of early and later work and because of differences in methodology, more work is needed to develop a fuller understanding of the development of evidence evaluation skills.

Integrated Components of Scientific Discovery: Studies of Self-directed Experimentation

Research on scientific reasoning that investigates participants' thinking and behavior during self-directed experimentation integrates the component processes of experimentation and evidence evaluation discussed in the two previous sections. Early scientific reasoning research on isolated component processes had several advantages, including a high level of control over the task and the ability to make direct comparisons of how different groups of participants engage in the task. However, to fully understand the scientific reasoning process, studying the integrated processes is necessary and offers significant benefits unavailable using previous methodologies. First, self-directed experimentation tasks are more authentic because they share more features with real scientific activity in both science laboratories and everyday settings. Individuals typically engage in all scientific reasoning components and they both initiate and control their exploration of a multivariable causal system. Second, even if the component processes were understood individually, a complete understanding of scientific thinking would include knowledge about how these components are integrated. Much of scientific reasoning involves the process of cycling through hypothesis generation and revision, experimentation and evidence evaluation. Thirdly, these studies typically have one of two main types of systems, physical "hands-on" systems or computer simulations, and these offer researchers the ability to control participants' prior relevant knowledge and the "state of nature" (Klahr, 1994; Zimmerman, 2000).

As researchers of scientific reasoning processes turned their focus toward integrated components and participants' reasoning on self-directed experimentation tasks, a model of scientific reasoning was developed. The Scientific Discovery as Dual Search (SDDS) model describes scientific reasoning as a form of problem solving that is a guided search and information gathering through two related problem spaces: a hypothesis space and an experiment space (Dunbar & Klahr, 1989; Klahr & Dunbar, 1988). Search in the hypothesis space can be guided by both prior knowledge and experimental outcomes; while search in the experiment space may be either guided by a current hypothesis or it can be used to generate information for formulating hypotheses. An important constraint on this search is the design of experiments that produce interpretable outcomes. Once unconfounded experiments have been conducted, evidence is available for interpretation. The evidence evaluation process influences search in both the hypothesis and experiment spaces as it assesses the fit between the current hypothesis and the evidence and guides future search in the both spaces (Klahr, 2000). An important feature of the SDDS model is that it can support a deeper understanding of scientific thinking by integrating scientific concepts and strategies and by discussing how people engage in the component processes to move through the hypothesis and experiment spaces.

Early work on integrated components introduced a method of investigating scientific thinking in the laboratory by engaging participants a situation in which they were to discover a rule that guided the behavior of a moderately complex system (Dunbar & Klahr, 1989; Klahr & Dunbar, 1988). Several features of this task make it a particularly fruitful method for investigating scientific reasoning processes: the system was complex enough that the hypothesis and experiments space are distinct, prior knowledge could be used to influence hypotheses (in this case about the linguistic and programming meanings of ‘repeat’ (RPT key) and knowledge of BigTrak robot used in the task), participants designed their own experiments, and they decided when they have discovered the correct rule (Klahr, 2000). Because participants could generate several theories about how the system operated, the task challenged their ability to write informative experiments and relate the outcomes to their theories.

The first in a series of related studies investigated adults' coordination of search processes and the role of evidence (Dunbar & Klahr, 1989; Klahr & Dunbar, 1988). This study of undergraduates revealed two distinct strategies used in scientific discovery: those of theorists and experimenters. Participants were classified as "theorists" if they proposed the correct rule without having produced evidence to support that hypothesis and they were classified as "experimenters" if they came up with the correct rule only after generating evidence to support that rule. Experimenters ran more experiments (without explicitly stated hypotheses) than did Theorists; Experimenters explored 50 distinct experiments, whereas theorists conducted only 19. Overall these adult participants performed well, with 19 of 20 discovering the correct rule, though no participant started out by proposing the correct rule.

Building on these early findings, a second study investigated 2 questions: is it possible to think of the correct rule by searching only hypothesis space, and when hypothesis space search fails, will participants switch to experiment space search? When participants were asked to generate as many different hypotheses about how the RPT key might work as possible, participants, compared to those in the first study, made discoveries in much less time, conducted fewer experiments, and switched hypotheses more easily. These studies illustrated that when adults engage in scientific discovery, some more naturally explore the hypothesis space and conduct experiments to confirm hypotheses, while others prefer to search the experiment space in order to induce hypotheses. When prompted to first explore the hypothesis space, participants then considered more than one hypothesis at a time and therefore they sometimes proposed the correct rule before gathering evidence. They thus designed better experiments, enabling them to discriminate between hypotheses. By considering several possible hypotheses before experimenting, participants were more likely to correctly respond to evidence that disconfirmed their current theory.

As presented in the first sections of this review, children demonstrate particular competences and difficulties across the various experimentation and evidence evaluation tasks when these processes are isolated. Therefore, studies of children's performance on tasks with integrated scientific reasoning components could build a richer understanding of the development of scientific reasoning processes. Developmental questions have been explored in both rule discovery tasks like those described above as well as in tasks involving multivariable systems in which participants work to discover the causal status of variables (Klahr, 2000; Schauble, 1990, 1996).

To better understand children's abilities, 8- to 11-year-olds' scientific discovery processes were examined using similar tasks (Klahr, 2000). Even with extra support (children were guided to a new type of experiment if they were currently investigating an incorrect hypothesis or if they ran four of the same type of experiments in a row), less than 10% of children discovered the correct rule, although more than half said that they were certain they were right. Children ran about the same proportion of unconfounded experiments as adults did, but they ran more experiments that were not able to help them decide between hypotheses. This study revealed three main differences between adults and children. First, although children had access to the same type of informative evidence, they generated different hypotheses than adults. Second, children also did not easily leave behind their current hypothesis or use the results from search of the experiment space to propose a new hypothesis. Lastly, when children did propose new hypotheses, they did not consider whether the hypotheses were consistent with prior results. In sum, children in this study had difficulty in discovering the highly implausible rule for the

RPT key. The next study, however, explored differences between adults and children when RPT held more commonly proposed rules.

To further explore developmental differences in participants' abilities evaluate plausible and implausible hypotheses, a similar task on computer was presented four age groups (university undergraduates, community college adults, 11- and 8-year-olds) Klahr provided each participant with an initial (incorrect) hypothesis that was viewed as plausible or not, and was either a little wrong or very wrong (Klahr, 2000). Participants were asked to write programs, predict behavior of the system, and instructed to talk aloud. The more plausible rules were easier to discover than the less plausible rules although children's performance accounted for most of this difference. When the rule was plausible, 75% of children discovered it, but when it was less plausible, none of the 8-year-olds and only 35% of 11-year-olds discovered the rule. An important developmental difference was related to participants' abilities to respond to a given hypothesis; adults were able to consider both the given and an alternative hypothesis and design experiments that could produce evidence to discriminate between competing hypotheses, whereas children could not. When children did propose alternative hypotheses, they generally focused only on that hypothesis and tried to produce convincing evidence for it, rather trying to produce evidence to that could help differentiate the two hypotheses. The ability to consider multiple vs. single hypotheses affects the type of experimental goals set by the participants, which in turn can be used to impose constraints on search in the experiment space. An additional important difference was that the youngest participants were the worst at understanding and verbalizing the cognitive constraints from domain-general knowledge; they did not make comments about distinguishing one step from another, designing short experiments, or using smaller number, and made in general fewer metacognitive statements.

This series of experiments informs us about similarities and differences in how children and adults reason about hypotheses and design experiments to evaluate them. Most 11-year-old and some 8-year-old children appreciated that in this context, they were to design experiments to generate evidence to support their hypothesis. Klahr asserts that contrary to the early claims of Kuhn et al. (1988) that confusion of theory and evidence persists through adulthood, even children were found to distinguish theory and evidence (Klahr, 2000). However, these studies illustrated important ways that when compared to adults both with and without science training, children's coordination of search in the hypothesis and evidence spaces was greatly inferior to that of adults.

Also exploring developmental questions, Schauble investigated the scientific reasoning of 10- and 11-year-olds as they experimented over 8 weeks to determine the causal structure of a computerized racecar microworld (Schauble, 1990). Building on previous studies that looked either at knowledge-lean tasks to study process, or process-lean tasks to study concept formation, this study made an early attempt to involve both content and process to explore the role of prior knowledge and experimentation strategies on children's belief revision. Children in the study built racecars that could vary on 5 features that were either causal or non-causal. In addition, children generally believed some features to be causal and other not causal (and were correct approximately half of the time). Therefore half of their beliefs were correct and half would need to be revised.

Overall, children understood much of the causal structure of the microworld at the end of the study. Children's processes however did not seem to follow either a "generate all possible cars" strategy (producing a complete factorial array) or Vary One Thing At Time strategy, and instead seemed mostly unsystematic. Children also did not make use of either their logbooks or the computerized records, and when they did use them, they did not update or integrate the information. This is not surprising, however, as previous work by Siegler and Liebert (1975) demonstrated that 10-year-olds were less aware of memory constraints, and did not use records even on a less complex task focusing only on the experimentation aspect of scientific reasoning.

Schauble (1990) categorized children's experimentation abilities. Their exploration processes typically belonged to 4 categories: planning, making comparisons, making judgments, and providing justifications. Children often used prior theories in many phases of the task, and as in previous studies (e.g., Tschirgi, 1980), children appeared to be trying to replicate desirable results, rather than understand relations between variables and car speed. When children did make valid conclusions (about confirmed variables) they often based their judgments on invalid evidence. When children made judgments about disconfirmed theories, they made some judgments influenced by evidence, but used many invalid judgments as a way to hold onto their theory. Unlike adult Theorists or Experimenters, where adult "experimenters" knew that the evidence generated should be used to revise theories and adult "theorists" knew that evidence could verify their theories (Klahr & Dunbar, 1988), children in this study appeared to think exclusively in one problem space or the other. They sometimes moved between the spaces but without understanding the impact of activity in one space for the other. Overall children's theories were observed to come closer in alignment with evidence, but not necessarily by conscious or reasoned decisions.

Following the early work of Klahr and Dunbar (1988) and Schauble (1990), more recent research on self-directed experimentation has further developed the understanding of how individual children and adults engage in scientific reasoning (Chen & Klahr, 1999; Klahr, 2000; Klahr, Fay, & Dunbar, 1993; Okada & Simon, 1997; Penner & Klahr, 1996; Schauble, 1996;

Schauble, Glaser, Raghavan, & Reiner, 1991, 1992; Schauble, Klopfer, & Raghavan, 1991). General findings regarding the development of integrated scientific reasoning components were summarized in the Zimmerman (2000) review of studies of self-directed experimentation studies. In terms of answering developmental questions, although self-directed experimentation research focused on both adults and children, few studies actually had a true cross-section of ages to compare abilities and deficiencies on the same tasks. As Zimmerman (2000) notes, although developmental generalizations should be considered tentative, children have been observed to "generate uninformative experiments, make judgments based on inconclusive or insufficient evidence, vacillate in their judgments, ignore inconsistent data, disregard surprising results, focus on causal factors and ignore non-causal factors, be influenced by prior belief, have difficulty disconfirming prior beliefs, [and] be unsystematic in recording plans, data and outcomes" (pp. 129-134). In microgenetic studies, 10-and 11-year-old children gradually improved over time and exposure to the tasks, and showed improvement in the percentage of valid comparisons, judgments, and evidence-based justifications (Kuhn et al., 1995; Kuhn et al., 1992; Schauble, 1990, 1996; Schauble, Klopfer et al., 1991). Over time and with repeated exposure to tasks, children better attend to and control factors and begin to distinguish between informative and uninformative experiments (Zimmerman, 2000).

Children were not alone in exhibiting less than ideal scientific reasoning, and adults' behavior was also influenced by prior beliefs. Adults performed better than children in that they typically waited for the results of several experiments before arriving at a theory, and instead of ignoring surprising results, they tried to interpret them. Adults generally made more valid comparisons by using a VOTAT or control of variables strategy (CVS). Adults were more likely like to consider more than one hypothesis at a time (Klahr et al., 1993), which was an aspect of scientific reasoning that was shown to contribute to success on a task (Schauble, Glaser et al., 1991). Adults, along with children, exhibited several strategies when exploring novel problem solving situations. The use of multiple strategies is not unique to childhood or developmental transitions, as microgenetic studies have illustrated how multiple strategies exist and are used at the same time (e.g., Schauble, 1990; Siegler & Crowley, 1991). As new strategies develop, such as beginning to use the valid CVS or VOTAT strategy over the less valid HOTAT or Change All strategies, they do not immediately replace the former, less effective strategies.

The increase in sophistication of scientific reasoning abilities of adults and children involves both strategy changes and the development of knowledge (Zimmerman, 2000). These important components impact one another, for as more sophisticated strategies support the development of more accurate knowledge, appropriate knowledge supports the selection and use of improved strategies (Schauble, 1996). Research that included both adults and children has shown that both groups demonstrate similar strategy development, even if adults were able to outperform children (Kuhn et al., 1995). Although more recent scientific reasoning research has been able to describe interaction of knowledge and strategies and the interaction between the experimentation, evidence evaluation and theory revision components of scientific reasoning, more work is needed to develop a more integrated picture of children and adults' scientific reasoning.

Parent-child Activity

Even very young children, while exploring the world around them, engage in scientific reasoning activities (Callanan & Jipson, 2001; Gopnik, Meltzoff, & Kuhl, 1999; Korpan et al., 1997). Understanding more about social contexts of learning is essential in understanding early development, as children often engage in early learning activities with parents, siblings, and peers. Families regularly engage in scientific discovery in both structured and unstructured activities and settings that may or may not be explicitly about science (Callanan & Oakes, 1992; Schauble, Beane, Coates, Martin, & Sterling, 1996). The second Research Question focuses on how parents engage with children in joint scientific reasoning, support their learning, and facilitate transfer. In order to address these issues, these next two sections will discuss research that has examined how parents engage in reasoning tasks with children in laboratory and everyday settings. These early experiences can impact children's development in many important ways. Early parent-child shared activities establish a learning relationship between parents and children, and this relationship could enrich children's understanding of science (Callanan & Jipson, 2001). Additionally, early experiences of parent-child joint activity begin to develop patterns of exploring and thinking together (Fagot & Gauvain, 1997). People's actions, attitudes, goals, and understandings in shared activity combine to create the meaning of their activity (Forman & McPhail, 1993). Engaging in everyday and informal scientific reasoning activities can expand what children know about science and scientific processes, but beyond this, early exposure to science can help to instill feelings of interest, competency, and value; children may come to view science as a part of their identity.

Children's earliest problem-solving activity often occurs in the presence of and is supported by parents (Rogoff, 1990). Because cognition has become to be viewed by more and more researchers as a collaborative process that emphasizes the achievement of shared thinking, researchers have begun to investigate how parents and children engage in learning activities together across a variety of contents and contexts and to explore how parent support impacts young children's learning (e.g., Beals, 1993; Callanan & Jipson, 2001; Callanan & Oakes, 1992;

Crowley & Callanan, 1998; Crowley, Callanan, Jipson et al., 2001; Fagot & Gauvain, 1997; Gauvain, 2001; Wood & Middleton, 1975). Unlike scientific reasoning research that mostly focuses on older school-aged children, studies of parent-child learning, whether conducted in the laboratory, home, or other everyday contexts, have focused on preschool-aged children. As children enter school, the research on social processes of learning changes focus from parents toward the role and impact of teachers and peers (Forman & Ansell, 2002; Forman & McPhail, 1993; Gauvain, 2001; Schauble et al., 1996).

In recent years, sociocultural perspectives have influenced both theory and research in cognitive development, with more and more work turning its focus toward social contexts for learning (Forman, Minick, & Stone, 1993). A central component of sociocultural theory is that children participate in cultural activities, which allow them to internalize the community's tools for thinking. As described by Saxe (1992), components of collaborative problem-solving activity, such as establishing goals, are often a blend of sociocultural processes and individual thinking activity. Goals that emerge during collaborative activity often take form and shift as individuals make particular contributions to the problem-solving process. It is important then for researchers interested in cognitive development to consider both the social roots of the tools for thinking that children learn to use as well as the social interactions that guide children in their use (Rogoff, 1998). Studying the activities that people engage in is also important because the values, assumptions, resources, and goals of the group are reflected in the activity (Wertsch, 1985). This "activity theory" approach to studying human cognition and development focuses on the role of social and cultural experience in formation of higher mental functions. The three important principles of activity theory are described as being "(1) that behavior is goal-directed and practical, (2) development is a product of social and cultural history, and (3) cognition is a socially mediated process" (Gauvain, 2001, p. 48).

Sociocultural approaches to cognitive development, which developed out of the early writings of Vygotsky in the 1920s (Vygotsky, 1962, 1978, 1987), attend to both the social forces that support and shape intelligence as well as to the social and cultural conditions in which intelligent members of society operate. Children, the young and inexperienced members of a community, are introduced to and taught about these ideas and materials, which supports their continued learning. Sociocultural theorists, such as Vygotsky and Leont'ev and their colleagues, argued that individual development was really a part of cultural and historical activity, for human beings interact with environments that have been developed by ideas and artifacts of previous generations (Gauvain, 2001).

Particularly useful in studying parent-child activity is Vygotsky's concept of the zone of proximal development (ZPD), which suggests that much of cognitive development occurs in social situations with children's problem-solving activity is being guided by adults or more experienced members of society who can structure activities and model problem solving strategies (Fagot & Gauvain, 1997). The ZPD is useful in understanding more about the difference between what a child can do on her own and what she can do in collaboration with a more knowledgeable partner and focuses on how the child gradually takes on more and more of the adult's role in structuring the activity (Litowitz, 1993).

Another useful tool for analyzing and understanding parent-child activity is the three-tiered framework described by Leont'ev which proposes three levels of analysis of collaborative activity: motive systems, goals, and operations (Leont'ev, 1981; Renshaw, 1992; Wertsch, Minick, & Arns, 1984). The most global level of analysis is the motive system, which organizes participation in everyday activities, providing a socioculturally-defined environment in which participants coordinate their purposes. This coordination enables people to maintain predictable sense of the ongoing interaction. The “goal” is the second level of analysis, which considers the particular task participants are engaging in, such a solving a puzzle. Although the completing the puzzle could be a single, common goal, the motive for doing so could differ. For instance, completing the puzzle could fulfill a work motive (for a job), an educational motive (to teach the skills involved in solving a puzzle), or a play motive (for relaxation and enjoyment). The third level of analysis is the operations, or specific actions employed to complete a task. An important aspect of this framework is that these three levels of analysis should be studied to explore the relationship of the levels rather than isolating each level for analysis.

Despite the fact that consideration of social contexts of cognitive development is increasing, Rogoff (1998) states that many sociocultural scholars still struggle with how to reformulate ideas about individual development to include and be consistent with sociocultural assumptions and to employ appropriate research methods. Rogoff argues that much sociocultural research actually continues to focus on the individual as the unit of analysis while adding in social factors as external influences; this type of research can be categorized as the “social influence” approach. Rather than focusing primarily on activity as the unit of analysis, the social influence approach continues to focus on the individual, however places importance on social contexts in which learning and development occur.

Useful in analyzing parent-child activity is Rogoff’s notion of intent participation, as shared family activity is often characterized by collaborative participation with children engaging in keen observation and listening (Rogoff, Paradise, Arauz, Correa-Chavez, & Angelillo, 2003). As parents and children engage in a shared task, their activity is often shaped by parent support. Learners observe, seeking understanding beyond imitation, in order to engage in activity in which they coordinate with others and this observation is often accompanied by pointers from more experienced partners. Sometimes the goal of the activity shifts to move beyond children's successful engagement in the activity to shaping their understanding of the experience to be more like adults'. It is here that additional layers of talk beyond what supports execution of the activity is often necessary to bring children closer to the adults' level of engagement and understanding of the task. Thus, communication in intent participation employs language to provide or discuss needed information during shared activity (Rogoff, et al., 2003); Rather than simply delivering bits of knowledge, conversation takes place in the context of the process being learned to enhance engagement. An additional important aspect of this concept is that both adult guidance and children's active participation in the shared task combine to benefit children's engagement and learning. Understanding more about the impact of patterns of interaction and conversation is particularly important because, as will be discussed in more detail later, research has shown that parents and children interact over time in ways that are consistent with previous patterns (Fagot & Gauvain, 1997).

Central goals of research exploring everyday activity – often being guided by the social influence approach – are identifying the activities that parents and children engage in together, identifying parent behaviors that shape the activity, and exploring the impact of the observed behaviors. Studies conducted in the laboratory, home, and other everyday settings place varying weight on each of these goals based upon constraints of the setting. Although research on parent-child learning in the laboratory setting is controlled and informative, it sacrifices the authenticity of observing spontaneous activity in everyday settings. To better understand how natural parent-child conversation patterns and topics occur, research has investigated parent-child interactions in the home. The research conducted in everyday settings that observes spontaneous activity in the home, in parks, or in museums is valuable because it informs us about the patterns and characteristics of these interactions and activities. Studies in the home or laboratory, though they the sacrifice authenticity, offer more control (as discussed above in the development of scientific reasoning) and can possibly better answer questions concerning the impact of particular behaviors. The studies of parent-child activity discussed in the following sections were conducted both in the laboratory and in the home and help to develop a better understanding of the activities parents and children engage in and how they impact the development of children's reasoning and problem solving.

Parent Support of Children's Theory and Concept Development

Focusing attention is the first step in learning about something. Therefore, research on very early parent-child activity has explored how parents help focus children's attention. Because directing attention does not require language, but can rely on eye gazes and gestures such as pointing, research has been done even with young infants and their parents. The getting and granting of attention characterize many parent-child interactions early in the child's life. Even young infants are active participants in the process and communicate to caregivers when their interests and needs are and are not being met (Gauvain, 2001). These very early processes have lasting impacts on what children learn about the world around then, as evidence has shown that maternal encouragement of attention with infants as young as 5-months-old was a predictor of 13-month-old children's language comprehension and competence (Tamis-LaMonda & Borstein, 1989)

As children become older they can rely on language to support increasingly complex interactions with parents, and research on early language learning has often observed how parents and children interact while engaged in picture book reading. As children learn language they also are learning about relationships between objects, and work in this area has found that early parent-child collaborative activity assists children's learning about concepts and categories. Observing mothers and children between 20 and 35 months of age while reading picture books, Gelman et al. (1998) found that mothers made many types of statements about objects and features of the world that provided opportunities for children to learn new concepts. To help do this, mothers directed children's attention to whole objects, rather than to just parts of objects, made comments about object identity, relationships between objects, and general information about objects. Also, in labeling objects, parents relayed complex category information. This study did not assess how children may have used or interpreted this information, but the fact that parents shared these types of information with children younger than 2-years-old suggests that these conversation patterns are rich contexts for children to learn about the world. In another study of storybook reading, Senechal, Thomas, and Monker (1995) studied how 4-year-old children of high or low word knowledge acquired vocabulary. Children who answered questions, pointed, or labeled objects during book reading understood and produced more words than did children who passively listened to the story. Therefore, if parents are able to actively engage children in verbal or nonverbal responding during storybook reading, they can significantly enhance children's vocabulary acquisition.

Beyond language learning and early concept development, parents sometimes help further children's theories of how the world around them works. Callanan and Oakes (1992) in a diary study exploring 3- to 5-year-old children's "why" questions, revealed that parents provide young children with rich causal information that can help them to build causal theories about how everyday objects and events function. These studies across various activities with children throughout the preschool years have shown that parents assist children's learning by directing their attention, by actively engaging them in joint activity, and by answering questions. These studies demonstrate ways that parent-child activity and conversation impacts children's daily reasoning and learning, helping children to acquire knowledge and develop concepts and form theories.

Parents and Children Engaged in Joint Problem-solving Activity

Much of early play activity, especially while exploring new objects, can be viewed as problem solving. As children engage in these processes, they typically do so under the guidance of adults (Rogoff, 1998). The process of an individual working on a problem could be much different than the process of solving a problem when multiple people work together. This can be especially true when people of various ages and abilities work together, as is often the case during everyday activity. A sociocultural approach to studying cognition focuses investigations more specifically on whether collaborative problem solving, for example, impacts what children encode and whether the social world plays a role in children's selection and use of problem solving strategies (Gauvain, 2001).

In order to explore the types of assistance and parents provide on problem solving tasks and to determine the impact of parent assistance, studies of parent-child problem solving are primarily conducted in the controlled setting of the laboratory. In an early study of encoding, mothers were observed while working with 3- to 5-year-old children to construct a difficult pyramid of blocks (Wood & Middleton, 1975). Mothers were asked to assist children in such a way that they could then complete the task alone. This study identified four strategies that mothers engaged in to teach children; demonstration, verbal, swing (alternating from demonstration to verbal and back to demonstration), and contingent (using a variety of strategies contingent on the child's success or failure). Children whose mothers employed the contingent strategy were the most likely to perform effectively after instruction. The authors likened effective instruction to a dynamic, interactive process similar to problem solving and discussed their view that intellectual development is a social, interactive process. In a follow-up study, Wood, Wood, and Middleton (1978) had a trained instructor working with children of the same age on the same task. The trained instructor provided children with one of the four instruction strategies that mothers had been observed using. The findings from the naturalistic parent instruction were replicated; the contingent strategy group performed significantly better than the other three strategy groups, which did not differ from one another. Similarly, in another study of mothers' instruction practices during problem solving, Saxe, Guberman, and Gearhart (1987) observed mothers and their 2.5- to 4.5-year-old children as they played number games together. The mothers' instruction was tailored to children's needs on the task, and they adjusted the goals of activities to be in alignment with children's ability. In turn, children were observed to adjust their goals to their mothers' attempts to organize the activity.

To more fully understand encoding processes, other problem solving research has explored where children were looking and who regulated eye gazes. Wertsch, McNamee, McLane, and Budwig (1980) recruited mothers and their 2-and-a-half, 3-and-a-half, or 4-and-a-half-year-old children to work together on a puzzle. The authors viewed a child's eye gaze to the model puzzle as a measure of how well the child was following an effective strategy. This study found that there was a decrease in proportion of eye gazes regulated by the adult with increases in age, which was viewed as an increase in self-regulated strategic behavior. When older children gazed at the model, they were likely to independently complete the next appropriate steps in completing the puzzle. Following self- or other-regulated gazes at the model, younger children were more likely to need adult assistance; younger children either were unable to extract the information needed from the model or were unable to use this information to make decisions about what steps to take next.

These studies problem solving focused on encoding and demonstrated that parent support impacts children's encoding and thus benefits children's performance and learning during joint problem solving activity. Other problem-solving research has focused on strategy choice and usage to determine how that is influenced by adult-child interaction. In a microgenetic case study analysis, Wertsch and Hickmann (1987) demonstrated that early strategic development is in fact developed through parental assistance. Parents provided "other-regulation" which allowed preschool-aged children to successfully engage in the activity at a younger age than they would have if engaging in the activity alone. In an experimental study, Freund (1990) compared the performance of 3- to 5-year-old children who either worked with their mothers or alone on a sorting and classification task of miniature furniture in rooms of a dollhouse. Children who practiced sorting alone were given corrective feedback by the experimenter. Children who worked with their mothers produced more "adult-like" categories than children who were provided corrective feedback while working alone. When mothers provided assistance that was classified as high level (talk that included strategy information), children's posttest performance was more accurate. Mothers were observed assuming more task responsibility and regulated the task more for younger children and for both ages of children when the task demands increased. These findings, replicated in other more controlled settings with strategy information provided to children by the experimenter (Crowley & Siegler, 1999), show that children can learn about strategies for solving problems from exposure to adult strategy use during joint problem solving. Not only do these studies demonstrate benefits of social interaction on children's performance, they show that during problem solving activity, adults are able to provide encoding and strategy assistance that is sensitive to children's needs.

Other laboratory studies investigating the impact of collaboration or "adult" support do not necessarily investigate parent assistance, but help to elaborate understanding of particular kinds of assistance by having participants engage in tasks with experimenters. Goncu and Rogoff (1998) investigated 5-year-old children's performance on categorization tasks following involvement in shared thinking when varying levels of support were provided. The two groups of children were given support: those children who were provided the categorization system and those children who the adult experimenter had induced to determine the categorization system, performed equally on the task and better than children who were given little support. Therefore adult assistance was shown to benefit children's later performance even when children did not devise the strategies or develop the knowledge on their own. As long as the children were actively participating in the task, there were no differences found between children who devised the information (strategies, explanations, categorization systems) themselves or who were told the information by the adult (Crowley & Siegler, 1999; Goncu & Rogoff, 1998). Overall, both adult guidance and active child participation play a role in supporting children's performance and learning.

Because not all parents assist their children in similar ways and because parent assistance has been shown to impact encoding and strategy use during problem solving, additional work is needed to explore what influences how parents assist their children. In a longitudinal study of mother-child problem-solving during the preschool years, maternal ratings of child temperament and observations of mother-child activity, measured at 18 months, were examined as predictors of mother-child problem solving behavior at 30 months and children's independent problem-solving at 5 years (Fagot & Gauvain, 1997). This study provided evidence that mothers' perception of the children's temperament and the guidance they provide influenced children's problems solving abilities over time. This study begins to answer the questions about whether early characteristics relate to later developments, as the results showed that parents and children interact over time in ways that are consistent with their previous patterns. The authors suggest that transaction patterns may be established in these relationships in ways that cumulatively impact development. The varied research on parents and preschool children has shown through studies situated in the laboratory and home settings that parents support preschool children's problem solving activity in a variety of ways. Parents assisted children's encoding by directing eye-gazes and based their level of guidance on children's specific needs and this assistance was shown to have long term impacts on children's problem solving abilities.

Parents and Children Engaged in Daily Conversation

While engaged in exploration of objects, parents and children may or may not take advantage of the opportunity to engage in scientific reasoning or to discuss scientific content. Some activities, seemingly unrelated to science, still offer opportunities to engage in science processes. Unlike during problem solving, where successful completion of the activity is the primary goal and conversation is a secondary layer, sometimes having a conversation is the primary activity as in Callanan and Oakes (1992) study of children's questions that arose during mundane activities such as bath time, mealtimes, and riding in the car. Scientific reasoning does not necessarily need to be situated within a particular activity, but rather can take place during daily tasks. Parents recorded children's questions about "how things work" and "why things happen" over a period of 2 weeks. The fully formed questions parents were asked to record (as opposed to open-ended "whys" that may function as conversation extenders) could reveal the types of causal mechanisms and links children are trying to better understand. In addition to learning about the questions, by recording the ensuing conversations, much can be learned about how parents respond with causal explanations. In addition to helping children to learn domain content knowledge, parents' responses help children learn about the processes of explanation and reasoning. Children aged 3- to 5-years-old were reported to ask questions in a variety of situations, including in the car, away from home (doctor's office, restaurant) or at home (while eating, bathing, reading, playing together, etc.). Questions covered a range of topics and types. The majority of questions took place at home (61%) or while riding in the car (27%). The most frequent type of causal explanation parents provided focused on mechanism, followed by prior cause, and consequence.

Overall, children's questions did reveal that they were actively seeking answers about how things work and why things happen. Because this diary study asked parents to report any questions of these types, they showed that questions, and thus explanations, varied in topic, forms, and situations. Because very few of the questions arose while families were reading or playing together, these types of interactions would likely have been missed by more traditional methodologies employed in the laboratory setting. It was observed that children who asked why and how questions predominately received explanations from parents that relating prior cause or mechanism information to children. Therefore, if this develops as a pattern of everyday parent-child exchange, children can use these questions to engage in conversations that help them to learn more about the process of causal explanation.

In another study of parent-child explanatory conversations, Beals (1993) recorded low-income families' mealtime conversations with 3-, 4-, and 5-year-old children. The study investigated two main questions: 1) whether or how often explanatory talk occurred in low-income families and 2) what was the content of explanatory talk to which preschoolers were exposed. Nine categories of explanatory talk were identified, and intentional explanations (of actions, commands, requests) made up nearly half of all segments. These types of explanations represent the importance to families to understand and explain their behavior and that of others around them. Over 15% of the mealtime talk was explanatory, although there was a great range between the families. Causal statements, the type traditionally studied by researchers, illustrating a cause and effect relationship made up 18% of explanations. Talk about evidence and procedures occurred in 7% of the explanatory segments. The author argues that conversation that takes children beyond the present and assumes a lack of shared knowledge aids children's cognitive and linguistic development. Explanatory talk, which allows children to make connections between ideas, objects, or events and that may or not be physically present, fits in to this description. More research is needed to determine the specific effects of these types of talk on children's language, literacy, and cognitive abilities.

Emerging evidence supports the view that parent-child conversation during novel experiences plays an important role in how children understand and encode shared activity (Haden, Ornstein, Eckerman, & Didow, 2001). When parents were provided training in an elaborative conversational style in which they were to ask *wh-* questions, make connections to prior knowledge, encourage elaborations, and offer praise, the engaged in these types of talk in greater amounts. Moreover, the talk appeared to focus children's attention on salient features of the activity, providing information that facilitates understanding, and served to organize children's resulting representations (Boland, Haden, & Ornstein, 2003). Children exposed to an elaborative conversational style were able to construct richer representations that they were then able to draw on in delayed memory assessments. In everyday settings, Tessler and Nelson (1999) suggest that this talk helps young children to make sense of shared experiences. Specifically, mothers who associated aspects of the shared activity with children' previous experiences had children who later remembered more about the activity than children of mothers who did not engage in these types of conversations.

Research on everyday conversations reveals that during activities like cooking or during mealtimes, parents and children share rich conversations during which they ask for and give information and causal explanations about a variety of physical and social phenomenon (Beals, 1993; Callanan, 1990, 1991; Callanan & Oakes, 1992; Callanan, Shrager, & Moore, 1995). Parents and children also sometimes engage in conversation about science as in Snow and Kurland (1996) where researchers observed mother-child conversation during exploration of magnets. These types of studies provide opportunities to look both at science content and processes. Greater than 90% of the dyads engaged in collaborative science talk about magnetization and parents' discussions of scientific processes were correlated with children's performance on measures of early literacy. This talk about science, including explanations, provided a context for extended discourse. The authors argue that these opportunities for science talk outside of school may help prepare children for science in the school setting. These conversations with parents, whether or not the activity is specifically about science, can support children's theory and category development and assist in children's developing scientific literacy.

Parents and Children Engaged in Integrated Scientific-reasoning Processes in Everyday Settings

Naturalistic studies both in and outside of the home allow researchers to directly observe parent-child interactions across a variety of activities. Laboratory studies that try to simulate authentic activity allow researchers to observe how parents and children engage in specific activities together, however laboratory tasks lose elements of choice and spontaneity. Science and children's museums have recently been explored as an example of a rich setting for parents and children to seek out and engage in interesting activities together, as well as to provide researchers an opportunity to observe this authentic, spontaneous activity. Studying naturally occurring activity is particularly valuable because the scientific component processes are integrated as parents and children explore their surroundings. As families generate and evaluate evidence to devise theories of how things work, parents can assist children's encoding processes and support their use of various strategies.

Many problem-solving situations are "ill-defined." In these types of problems, one or more of the problem-solving components (initial states, goal states, and steps to move toward solution) are unknown. Exploring new objects in everyday activity can often be characterized as ill-defined problem solving, as Schauble and Glaser (1990) discuss that experimentation is typically an ill-defined problem for children and adults. An example of this could be figuring out what a new toy does or trying to produce an effect at a museum exhibit. It is often the situation at museum exhibits that visitors approach an exhibit and are unaware of the actions to take to manipulate the exhibit or the effect it was designed to produce.

A line work by Crowley, Callanan, and colleagues has investigated the types of scientific activity, conversation, and collaboration families engage in while exploring museum exhibits

(Callanan & Jipson, 2001; Crowley & Callanan, 1998; Crowley, Callanan, Tenenbaum, & Allen, 2001; Crowley, Callanan, Jipson et al., 2001; Crowley & Galco, 2001; Fender & Crowley, 2004, under review). The majority of these studies, employing an observational methodology, demonstrated that parents and children, even with young children aged 1- to 8-years-old, engage in spontaneous scientific reasoning. Crowley and Callanan (1998) discussed several ways of describing and supporting parent-child collaboration during scientific thinking. Although science exhibits can be vehicles for relaying content information, the authors view science museums as settings for forming expectations, generating and evaluating evidence, and constructing explanations. With science being about making sense of the world, successful exhibits provide opportunities for children to work with parents in the coordination of theory and evidence. Parents were observed to be both guides and interpreters as they shape children's experiences at the exhibits.

The characteristics of parent-child activity was described in more detail in an observational study of families using an interactive science exhibit during visits to a children's museum (Crowley, Callanan, Jipson et al., 2001). Families were videotaped during spontaneous, undirected use of a zoetrope, a simple animation device with a series of animation frames inside a cylinder that spins. When children spun the cylinder and looked at the animation through the slots on the side of the cylinder, they saw animation due to the stroboscopic presentation of the individual frames. Overall, children who explored with parents, as compared to with peers or alone, were engaged with the exhibit longer, observed more evidence, and focused on more important comparisons of evidence. Parents were observed to help children generate evidence and describe evidence available. In nearly half of the interactions parents highlighted the relevant evidence by labeling it, and in more than one-quarter of interactions, went further by discussing ways of encoding the evidence. Parents were provided explanations to their children in more than one-third of parent-child interactions. Examples included talk about causal links within the local context ("The horse looks like it's running backwards because you spun this thing the wrong way"), talk that made a connection between the exhibit and prior knowledge or experience ("This is how cartoons work"), and talk about unobservable principles underlying, for example, the illusion of motion ("Because your mind… your eye… sees each little picture and each one's different from the other one, but your mind puts it all in a big row"). Because this study examined spontaneous activity, no posttest measures of learning were possible. However, because of the varied levels of parent support provided, children who explored the exhibit with parents had greater opportunities to learn.

In a second study designed to discover more about spontaneous everyday scientific thinking in museums, several hundred families with children from 1- to 8-years-old were videotaped while using 18 interactive science exhibits representing a broad range of scientific and technical content, including biology, physics, geology, psychology, engineering, robotics, and computers (Crowley, Callanan, Tenenbaum et al., 2001). Replicating the findings of Crowley, Callanan, Jipson, et al. (2001), parents were observed to provide explanation in about one-third of interactions. However, this broader study also revealed a gender difference: Parents were about three times more likely to offer explanations when using exhibits with boys than when using exhibits with girls. This finding suggested that, if parent explanation has any effect on children's learning, boys and girls may be learning different things from at least some kinds of everyday scientific thinking and thus may be developing different knowledge or attitudes about science before they encounter science instruction in elementary school.

In order to explore the specific impact of adult explanation children's learning during everyday scientific reasoning, a study of adults and children using the zoetrope was conducted using a mix of observational and experimental methodology (Fender & Crowley, 2004, under review). This allowed for exploration of the kinds of spontaneous and authentic parent-child scientific thinking that have been described in the previous low-impact observational studies (Crowley, Callanan, Tenenbaum et al., 2001; Crowley, Callanan, Jipson et al., 2001), while at the same time allowing for the measurement of the state of children's knowledge following the experience. Three groups were compared: Children who explored the exhibit alone, children who explored with parents who did not explain, and children who explored with parents who provided explanation. Children in all three groups demonstrated similar procedural knowledge about the device, but children whose parents provided explanation (like the examples above) were most likely to go beyond surface characteristics and make conceptual connections with analogous devices. Furthermore, there were no differences between children whose parents did not explain and children in the control group, suggesting that parent participation without explanation was not sufficient to support the deeper conceptual connections.

Because one of the goals was to study spontaneous, un-cued activity, a pretest was not possible in the previous study. Any pretest that measured specific knowledge of the zoetrope or general knowledge about animation might have cued children about how to encode the experience. Additionally, because of the nature of spontaneous activity, some parents decided to explain or to not explain. These parents, self-selecting their condition in the study, could have based this decision to explain on various factors, such as previous knowledge of animation or the child's interests and level of engagement with the task. A second study to explore the immediate impact of explanations, designed to introduce aspects of control typically found in laboratory studies while maintaining the location, activity, and the nature of explanation, involved an experimenter-guided exploration of the zoetrope and random assignment to groups. Half of the children, aged 5- to 8-years-old, were randomly assigned to either an explanation or non-explanation group. Children were given both pre- and posttests to measure how they encoded the exhibit and both what they knew about how the zoetrope works and how animation works. No group differences were found regarding children's knowledge of the zoetrope or how animation works. Replicating findings from the first study with spontaneous parent explanation, children who heard explanation had significant gains in encoding the exhibit according to deep features. Although all children were shown how to produce the animation effect, older children who explored the exhibit without explanation actually chose fewer animation objects when completing the posttest activity. Exposure to evidence and learning how to manipulate the exhibit did not provide enough support for even older children in the No Explanation condition to overcome the pull of surface features to encode the deeper function of the device. However, both older and younger children who heard explanations during their exploration were more likely to encode the device in ways consistent with the device's function.

These museum studies capture parent-child interactions that are surprisingly rich considering that they often only last between 30 seconds and a few minutes. Although these provide good examples of typical everyday brief engagements in reasoning tasks, they are not lengthy enough to allow for in-depth study of how parents and children integrate scientific reasoning processes. In order to explore lengthier parent-child activity, Gleason and Schauble (2000) recruited parent-child dyads to engage in scientific reasoning during a 45-minute exploration of a moderately complex system during which they attempted to discover the causal structure of the system. This study of parent-child scientific reasoning that builds directly on previous findings of children reasoning alone (Schauble, 1990, 1996). The children in this study were aged 9- to 12-years-old and these ages were chosen based on previous research findings that found that the particular scientific reasoning strategies of interest emerged during this time. Parents and children worked together generating and evaluating evidence, while sharing control of the exploration as this study explored three main goals: to characterize the parent-child strategies for generating and evaluating evidence in a multivariable context; to characterize how parents and children shared the tasks during the problem solving process; and thirdly, to identify relationships between the scientific reasoning processes and the changes in participants' content knowledge, or theories about the causal structure of the boat-canal system. The study's focus on these aspects makes it particularly useful as we move towards the discussion of the parent-child examples in this paper.

Focus 1: Joint Scientific Reasoning Process. Observations revealed that parents assumed greater control for the conceptual aspects of the task and delegated manual control of the system to children. Primarily parents consulted and recorded findings on the data cards and reviewed the design and outcomes of trials, while children operated the boat and timer. Dyads generated an average of 22 trials and therefore the interpretation of evidence grew to be a large task. Despite this, dyads only consulted the records on a little over half of the trials. When they did consult the records, they jointly looked at them on 32% of the trials, while parents looked at them alone in 64% of the trials. In order to preserve the joint problem-solving atmosphere, this study differed from several previous studies (Schauble, 1990, 1996) of solo experimenters in that the participants were not asked at the conclusion of each trial if they would like to make an inference. Therefore, in this study the level of 48% of trials including inferences was lower than previous studies in which participants made inferences after nearly every trial (Schauble, 1996;

Schauble, Klopfer et al., 1991). Participants were observed holding off on making inferences until a cluster of trials was conducted. Inferences were coded as valid if correct and if made after conducting trials that varied only on the variable of interest. Eighty-five percent of participants' inferences were valid and parents alone made 67% of the inferences, while 16% were made by children alone, and 17% were made jointly by the dyad.

This study revealed that the processes of parent-child scientific reasoning were organized, however, the pattern of role taking that was observed might not be the most useful in helping children to learn about the processes and strategies of scientific reasoning. Parents did not take advantage of opportunities to share the reasoning behind how they structured the task.

Focus 2: Parent-child interaction. Patterns of parent-child interactions were explored along three dimensions: the kinds of assistance provided and to whom, who controlled the problem solving process, and the frequency of the collaborative discussions that occurred. In general, parents assisted their children more than children assisted their parents. Specific forms of parental behavior were observed that would likely help children's developing scientific reasoning abilities, such as the discouragement of conducting uninformative experiments, prompting to make predictions, and justifying predictions. These behaviors help children to better coordinate theory and evidence. In more than half of the trials (65%), parents were in control of what happened, with children in control for 9% and joint control in 26% of trials. Assistance and control were distinguished here, for in every trial it was necessary for someone to determine which actions were taken, whether shared control or parent or child sole control. However, there may or may not have been instances of assistance in every trial. For example, in some interactions, parents gave most of the assistance while they shared control with their child. In some of these cases, collaborative discussions emerged when parents and children resolved a disagreement, when they worked together to make decisions or agree on the interpretation a trial. Discussions that occurred before or during trials had parents and children discussing how to run the trial and which features to test. When these discussions occurred after the trials, parents and children collaborated on the interpretation of evidence and inferences that were possible to make. Collaborative discussions were identified on 40% of trials, with 71% of collaborative discussions occurring during the trial-planning phase. Parent control of the trials was found to negatively correlate with collaborative discussions, while shared control and collaborative discussions were positively correlated with collaboration. It was not possible in this study to determine if shared control led to collaborative discussions or if collaborative discussions led to shared control. They found that assistance also led to collaborative discussion, typically as a parent helped a child to complete a task.

Focus 3: Changes in Participants' Theories. Parents and children individually answered pre- and posttest questions regarding their beliefs about the causal role of the variables. Parents and children started the task with roughly equivalently accurate beliefs. Parents' and children's beliefs did not come into better alignment after experimentation, which was discussed as not surprising given the lack of evidence interpretation discussion. As previously mentioned, collaborative discussions primarily occurred during trial planning, which may help children to focus on scientific reasoning strategies. However, additional collaborative discussions during the evidence interpretation phase could have made children more active and more aware of valid inferences and interpretations.

This study provided very detailed information about how parents and older children engage in joint scientific problem solving on a structured task and how that activity does or does not result in learning. Future research might elaborate on these findings by focusing on changes in children's strategy use, investigating patterns of activity with parents supporting younger children's reasoning, or by looking at more spontaneous, natural tasks. Another direction to take this line of work might include measuring parent-child activity over time, which could allow for looking at the impact of particular patterns of parent assistance on scientific reasoning processes, in addition to content learning. This study did reveal one important finding in that parents often missed opportunities to provide assistance, especially in helping children to evaluate evidence in order to make valid inferences. One conclusion from these findings is that although parents, without prior knowledge of a task, are able to successfully engage in scientific reasoning tasks with their children, they would benefit from information about children's particular needs for support during scientific reasoning. Perhaps parents were not aware that their children were not able to reach the same conclusions they did based on available evidence (Gleason & Schauble, 2000).

To explore the impact of science and engineering goals on everyday activity, Kim and Crowley (in preparation) focused on whether museum exhibits signage with either science or engineering goals can impact families' goals for exploring a museum exhibit. Additionally, this work wanted to explore whether adopting these goals would impact patterns of parent-child scientific reasoning as well as what children would learn from that activity. Families engaged in self-directed exploration of an exhibit in which paper helicopters with various causal and non-causal features could be flown off of a two-story tower. Because this activity engaged families with preschool and elementary school children and because they determined when they were finished exploring, the interactions were much shorter than in the Gleason and Schauble (2000) study. Families explored this multivariable system for between 5 and 15 minutes and were provided goals through exhibit signage that orienting them towards either science goals (What makes a difference in flying time?) or engineering goals (How can we make a paper helicopter fly longer?). Families in the two conditions tested the same number of helicopters; however children in the scientist condition completed more possible controlled comparisons in the factorial evidence space than engineer children. Additionally, scientist parents took a more active role than engineer parents in talking to children and helping children design experiments. Following the exploration of the exhibit, scientist children were more likely to correctly identify factors as being causal and to correctly identify how different levels of factors were related to flying time. Thus, scientist parents responded to the science goal by providing higher levels of mediation by helping children structure comparisons, while engineer parents often stood back and let children explore on their own to find the longest flying helicopter. This appeared to affect learning: Scientist children learned about the entire variable space while engineer children learned about the specific tests they made, but failed to draw as many valid inferences about all variables. In fact, engineer children sometimes evidenced retrogressions, changing correct pretest models to faulty ones at posttest.

Research on parent-child activity has revealed many different ways that parents support children’s early development in areas such as concept learning, encoding, and strategy choice and use. This comes through mediation provided both during common everyday tasks and while exploring novel environments. As in the scientific reasoning literature, more cross-sectional research to provide a more complete picture of how parent-child activity changes over time and across tasks. Developmental psychologists, most often focus on ontogenetic development—the change in thinking and behavior that happens across time in the history of individuals. The research reviewed in this section focused primarily on this grain size of learning. Vygotsky also discussed three other time scales (microgenetic, phylogenetic, and sociohistorical development) and the importance of integrated study of these different time frames (Rogoff, 1998). Microgenetic studies of development, looking at moment-to-moment learning of individuals within certain problem solving areas (e.g., Siegler & Crowley, 1991), could be a particularly useful method to studying parent-child activity. Perhaps a microgenetic exploration parent-child scientific reasoning over time could improve understanding of the general patterns of parent-child activity that result in specific knowledge and particular levels of performance by children of different ages.

Literature Review Synthesis Points

This section returns to the Synthesis Points that were first presented before reviewing the development of scientific reasoning and parent-child activity literatures. The Synthesis Points elaborate characteristics of parents, children, and their shared activity that might shape the development of scientific thinking. Additionally, the Synthesis Points address issues related to considering parent-child activity as a context for studying the in vivo development of scientific reasoning.

Synthesis Point 1 – Goal Negotiation

During shared scientific reasoning, parents and children work together to negotiate the goals of the activity. Research has shown that aspects of people's scientific reasoning are modified by the goals that they set. For instance, when people adopt science goals, they work to understand what makes a difference, as compared to adopting engineering goals, where they work to produce a desirable effect. This issue becomes even more complex when more than one person is working on a task, as is the case during parent-child shared scientific activity. Misunderstandings can arise when parents and children are working with competing goals in mind. During mundane everyday activity, sometimes young children spontaneously adopt learning goals, as in Callanan and Oakes (1992) diary study. When children ask “why” questions, parents respond by providing causal explanations and engaging their children in learning conversations. However, during more structured tasks, parents typically set most of the goals when engaging in shared scientific activity (Gleason & Schauble, 2000). In this study, parents alone controlled what happened during nearly two-thirds of the trials, while parents and children shared control in about one quarter of trials. Everyday science settings could be constructed to support learning by making science goals more explicit and available to parents. As shown by Kim and Crowley (in preparation), when science goals (as opposed to engineering goals) were provided for parents and children, parents provided higher levels of mediation by taking on a more active role in talking to children, especially during the design of experiments. It was found following activity with parents in the science goal condition that children learned more about the causal status of the variables and were more able to draw inferences than children of families in the engineering condition. Therefore, in designing or studying everyday and informal learning environments, one needs to be sensitive to the different goals that people engaged in scientific activity might adopt and how that will impact their joint reasoning processes.

In answering the second research question through the exploration of parent-child activity and conversation, I will describe how parents and children engage in goal negotiation during shared scientific reasoning. By describing how parents and children share responsibility for the experimental activity we will understand more about how they either impose their own experimental goals or work together to establish and achieve shared goals. Furthermore, parent-child conversation will be coded for varying types of talk that establishes goals for the experimentation.

Synthesis Point 2 – Distributed Cognition

Parents and children engaged in joint scientific thinking is an example of distributed cognition, with each member playing a unique role. While engaged in scientific reasoning or problem-solving activities, adults can be particularly helpful to children when acting as memory, processing, or metacognitive support. Children's limitations demonstrated in laboratory studies with children working solo could arise from a combination of general reasoning and metacognitive deficiencies and as well as deficiencies in understanding the processes of scientific reasoning. When parents are able to support the cognitive load in complex reasoning tasks, children have more resources available to reason about more aspects of scientific activity.

Children often have difficulty considering more than one hypothesis at a time when generating experiments or evaluating evidence, which impacts how they explore the experiment space (Klahr, 2000). When focusing on one hypothesis at a time, children's experimental goal would be to find either evidence for or evidence against their theory. Parents could help children by reminding them of other possible theories. When able to imagine alternative states of the world, parents and children can attempt to design discriminating experiments that would provide evidence for only one of the competing theories. The design of this type of experiment is especially fruitful in that engages the reasoner in all three components of the scientific reasoning processes: hypothesis/theory exploration, experimentation, and evidence evaluation.

Beyond difficulties in considering multiple hypotheses, Klahr (2000) demonstrated that elementary school children engaged in self-directed experimentation also did not appreciate domain-general constraints, as they made the few comments about needing to conduct short experiments, being able to distinguish one step of the experiment from another, and using small numbers. Even when asked to focus on isolated components of scientific reasoning, elementary school children demonstrated difficulties; during experimentation they had trouble considering more than one variable and while evaluating evidence found it difficult to compare more than one category of evidence (Shaklee & Paszek, 1985; Tschirgi, 1980). When middle school children were working to discover a rule, the younger children were significantly less likely to keep records of the experiments run, but when they did so, were more likely to discover the rule. Research on parent-child joint activity with older children (aged 9- to 12-years-old) showed that parents took responsibility for recording findings, consulting records, and reviewing the design and outcomes of trials. Parents engaged in these behaviors alone in nearly two-thirds of the instances, and shared the task with children for the remaining trials (Gleason & Schauble, 2000). Parents often did not assist children in learning more about scientific processes because they did not share the reasoning behind the scientific activities they were engaging in.

In contrast, with simpler, age-appropriate tasks, research has shown that in joint problem solving with preschool children, parents are responsive to children's needs and provide appropriate levels encoding and strategic assistance. While working on a puzzle, older preschooler children were able to look at the model puzzle and independently complete the next steps. However, younger preschool children needed additional adult assistance to either extract the necessary information or to use that information to know what to do next, and parents responded by assisting their problem solving (Wertsch et al., 1980). In addition to encoding assistance, Freund (1990) showed that with increasing task demands, mothers provided greater assistance and regulation for both older and younger preschool children. More research with preschool and school-aged children is needed to better understand the problem solving and scientific reasoning activities in which parents provide appropriate assistance. Perhaps it is more obvious to parents that younger children need more general assistance, but less obvious what help is needed for their older children during more complex scientific reasoning.

To address the issue of Distributed Cognition, Research Question 2 again explores how parents support children's learning and transfer through activity and conversation. We will be able to explore parent talk to see how they remind children of what they learned together as children engage in experimental activity. Additionally, Research Question 1 is related to this issue, for if parents are able to take responsibility for particular aspects of shared experimentation, it may enable children to better attend to particular aspect of the activity, and thus better learn the strategy. Although not able to be related directly, if young children are able to succeed in learning the strategy, it may well be that distributing the cognitive load of the activity contributed to child learning.

Synthesis Point 3 – Systems of Shared Knowledge

Through joint activities, children and parents develop systems of shared knowledge about science content and about processes of scientific reasoning together. Prior knowledge influences how children and adults engage in experimentation and how they evaluate the evidence they encounter. Prior knowledge about a problem determines whether a problem is ill-defined or well-defined for the problem-solver. It is possible for parents who have had exposure to certain problems or types of scientific activity, that the problem is well-defined, but that for their child, it is ill-defined. In this situation, parents should be aware that perhaps their child might not know the goal of a particular task or the necessary steps to solution.

Experimentation can have two functions: discovery or confirmation (Klahr & Dunbar, 1988). For children who have no experience with particular task, their experimentation is about discovering a hypothesis. However, their parents could approach the task with prior knowledge or a theory of how things work, and in which case, their experimentation is about confirming their theory. In this way, prior knowledge could change the function of experimentation for children and adults. However, when children do have prior knowledge about a task, such as a theory of which variables in a system are causal, during experimentation they do use their prior knowledge and appear to try to replicate positive results rather than understand the causal status of the variables (Schauble, 1990).

Prior shared knowledge also impacts joint activity in that it changes what adults and children are able to discuss and reference during joint activity. When parents and children engage in various types of everyday scientific reasoning at home, in museums, in parks, and in their back yards, they build a common set of experiences to draw on during future joint scientific activity (Callanan & Jipson, 2001). Through this repeated joint activity, parents and children may develop extensive knowledge systems that have been referred to as islands of expertise (Crowley & Jacobs, 2002). Perhaps even more important than the content knowledge that is acquired, parents and children can use these islands as platforms for engaging in more sophisticated conversations and reasoning than would have been possible otherwise. Finally, patterns of scientific reasoning in everyday activities develop habits of thinking, wondering, and inquiring that become important components of children’s identity.

This study will extend our understanding of how shared knowledge impacts parent-child activity by investigating how parents and children reference prior shared experiences and use their learning in a subsequent related experience. By studying activity over time, it will be possible to investigate whether parents and children use knowledge of how they interacted together to shape future activity.

Synthesis Point 4 – Problems of Communication

Joint scientific thinking can be hindered by problems of communication. First, parents are often unaware that aspects of scientific thinking that are self-evident for parents can be difficult for children. Second, young children often know more than they are able to explicitly talk about with their parents. As children grow, they demonstrate reasoning skills of increasing complexity, and because of this, parents may not be aware of specific areas in which children even as old as 8- to 12-years-old need assistance. The aspects of scientific thinking that are easy or difficult for adults can impact how parents are able to assist children's reasoning and learning. It is particularly beneficial to compare and contrast adult and child performance on scientific reasoning tasks. Distinguishing which particular skills improve or mature as children develop from other skills or strategies are generally more difficult even through adulthood helps to identify areas that are in particular need of support, both for children and adults. Particular processes that are difficult even for adults can inform us of which areas in science classes or in science museum exhibits might need particular support.

Aspects of scientific reasoning in which adults do not have much difficulty might be the very aspects particularly ripe for parents to focus their support while engaging in scientific reasoning with their children. However, if adults find particular skills easy, they might not be aware that those particular areas are difficult for children and therefore may miss opportunities for assisting children's learning. Once parents understand more about children's particular scientific and general reasoning weaknesses, however, these areas may particularly benefit from parental assistance.

For example, during experimentation activity, adults exhibit proficiency under certain conditions, yet they experience difficulty in others. In being able to use appropriate experimentation strategies, children, and even adults, when trying to maintain a positive result, typically use a poor strategy: holding one (good) variable constant and changing all the others (Tschirgi, 1980). However, when wanting to eliminate a bad result, adults and children as young as 11-years-old appreciate the difference between appropriately holding one variable constant and the strategy of changing levels of all variables. Younger children still have difficulty applying the appropriate strategy under these conditions. The elementary school children focused only on eliminating the bad variable, even if that meant adopting the poor strategy of changing the levels of all variables. Parents could provide assistance to children in this area if they were made aware of this difficulty that children have in experimentation.

Once an experiment has been conducted, one needs to be able to evaluate the evidence that was produced and use it to make inferences. Younger children often have difficulty doing this and as Gleason and Schauble (2000) demonstrated, even 9- to 12-year-old children do not arrive at the same conclusions as their parents when presented with the same evidence during joint activity. As discussed, parents missed opportunities to share their interpretation of the evidence with their children and assist in comparative aspects of experimentation and evidence evaluation. Even during explorations of museum exhibits that last approximately 1 to 2 minutes, when parents provide brief explanation, children were more likely to encode the deep features of the exhibit (Fender & Crowley, 2004, under review). Even though sharing their interpretation with children is relatively quick and easy, typically parents only provide interpretation or explanation in less than one-third of interactions. Finding a way to alert parents to this easy, but highly beneficial way of enhancing children’s experience with everyday and informal scientific activity, both in and outside of the museum, could help bring parents’ and children’s understandings following joint activity into better alignment.

The second way that shared scientific reasoning is hindered by problems of communication is that young children often know more than they are able to explicitly talk about with their parents. Children can be learning content and procedures well before they are able to verbally express their new understanding during activity with parents. During everyday scientific activity children (and parents) can learn content knowledge as well as procedural knowledge about engaging in reasoning, questioning, and explaining generally and scientific processes more specifically. It will be important to consider this point not only from the perspective of the researcher who wants to better understand children's understanding, but from the perspective of parents, as well. When engaged in joint activity, parents who are aware of this possible issue would not necessarily shy away from engaging children in activity or talking to them about science concepts and processes that their children might not yet be able to talk about. Even preschool children are developing theories about biological, physical, and astronomical phenomenon (e.g., Carey, 1985; McCloskey, 1983; Vosniadou & Brewer, 1992). However, although these children are indeed thinking about science domain knowledge, we are not implying that they are intentionally or consciously engaging in scientific reasoning activity like that examined in this study. However, not only do young children acquire content knowledge at a young age while engaged in activity with parents, they also can use these theories to describe and provide causal explanations of events. Parents engage preschool children in science conversation, not only to learn content, but to learn about processes of science and of providing causal explanations (Callanan & Oakes, 1992; Snow & Kurland, 1996). Engaging children in these types of activities and conversations at an early age helps to develop patterns of engaging scientific activity as they grow older. Early exposure to science talk and explanation outside of school was correlated with early literacy measures, as well as helping to prepare children for science in school (Snow & Kurland, 1996).

Again, in exploring answers to Research Question 2 and looking at how parents support learning and transfer, we will describe whether possible problems in communication may have may have interfered with children's learning and transfer. Especially in discussing issues of miscommunication, age-related differences will be explored to compare how older and younger children engaged in the activity with parents, and turn, how parents engaged with older and younger children.

Conclusion

Scientific reasoning activities engage children in early learning opportunities. Through these activities children learn scientific content and about science as a field of study. Just as important as acquiring science knowledge is children's engagement in scientific reasoning processes; however, this is not limited to activities that are explicitly about science. Children's everyday exploration of the world around them engages them in constructing theories and hypotheses, as well as generating and evaluating evidence.

The reviewed scientific reasoning literature primarily focuses on the individual as the unit of analysis. Additionally, many studies focus on older children, aged 8- to 12-years-old. But to better understand how children's scientific reasoning processes develop, it is important to study where and when this development takes place. Preschool children spend much of their time in the company of parents as they collaboratively explore their environment. Exposure to these reasoning processes helps children to understand how to engage in reasoning, problem solving, and explaining. Children develop ways of asking and answering questions. During these activities, children not only engage in processes and learn about content, but they begin to develop lasting learning relationships with their parents. Additionally, they potentially develop as people who are interested in and who value scientific activity. Patterns of curiosity and wonder that are established early in life could persist as children develop into adults who perhaps become scientists or who continue to pursue science-related hobbies.

The parent-child learning literature reveals that parents have many conversational and behavioral ways of guiding and supporting young children's learning. From language learning and concept development to causal reasoning and strategy development, research has been conducted to understand children's abilities throughout development. Parents were observed to behaviorally and verbally direct attention and to assist in problem solving by providing encoding and strategy help to preschool children. Children engage their parents in causal conversation and elicit explanations in everyday settings, even in the midst of mundane daily activity, such as during meals or while riding in the car.

Parents and children often engage in everyday scientific thinking, and studying this type of activity helps to understand peoples' values, assumptions, and goals. These types of interactions are especially useful to study in order to develop a more complete understanding of how early activity might shape children's developing knowledge of scientific content and processes. This type of activity is likely not characteristic only of how museum exhibits are explored, but could represent brief moments of reasoning and wondering that parents and children engage in daily in various contexts. Further research is needed to explore whether the behaviors and patterns observed here might be consistent with family activity across content or contexts. Future work may reveal whether there are distinctive family-specific patterns that develop over time with exposure to particular activity. Klahr (2000) states that "successful scientists master two things: knowing where to look and understanding what is seen. Knowing where to look – experimental design – involves the design of experimental and observational procedures; the second – hypothesis formation – involves the formation and evaluation of theory." Researchers interested in understanding how children develop into successful scientists may want reconsider where they primarily look for answers – the psychology laboratory – and instead look towards in vivo interactions with parents. Doing so can provide additional information necessary to develop more complete theories of the development of early scientific reasoning. Additional work should be done not only to identify the types of activities and conversations parents and young children engage in, but to also determine their impact on the learning of science content, scientific processes, and developing interest in science. Further research is needed to better define causal links between specific parent and child behaviors and the development of early scientific reasoning.

Impetus for the Current Study

The current study expands upon previous findings in several ways. As described in this chapter, the scientific reasoning literature typically focused on older elementary-school children while the parent-child learning literature primarily focused on preschool-aged children. The study has been designed to first explore whether young children can learn a strategy for designing unconfounded experiments and secondly, to explore ways in which parents support learning and facilitate transfer during joint scientific activity. Addressing these two questions together extends the current literature, in particular, by exploring parent support of 5- to 8-year-old children's scientific reasoning. Describing relationships between specific parent behaviors and children's subsequent performance will expand our understanding of the processes involved in the development of scientific reasoning. Typically, recent research on parent-child activity has explored immediate learning outcomes; yet more work is needed to provide direct causal support to the longer-term learning gains that we hypothesize are the results of these patterns of activity. This study takes a step towards achieving this goal by exploring how parents facilitate transfer in a related task at a one-month delay and by beginning to answer questions concerning how parents and children build on shared knowledge over time.

CHAPTER 3

METHODOLOGY

Overall Design

The purpose of this study is to further elaborate our understanding of the development of scientific reasoning. Much of what is currently known about the development of early scientific reasoning was discovered in the laboratory context with individual children performing tasks designed by the researcher. This study investigates parent-child collaborative activity in order to explore the social contexts in which scientific reasoning skills often are developed and practiced. More specifically, this study is guided by the following research questions:

1) Can children learn and transfer a scientific reasoning strategy when provided training situated within parent-child activity?
2) How do parents support young children's learning and transfer of a scientific reasoning strategy? Are there age-related differences in the kinds and levels of support that parents provide?

To address these questions, the present study consisted of two Sessions, conducted one month apart. Both Sessions 1 and 2 consisted of 4 phases (see Table 1). Families were introduced to two tasks in which they engaged in the design of experiments to test the possible effects of different variables. Participants were asked to explore two tasks to determine, in Session 1, how Ramp variables impact how far the balls roll, and in Session 2, how Spring task variables impact how far down the springs stretch. In Phase 1.1, introduction and pretest, parents and children were presented with the materials and the three variables were described. Children and parents were given individual pretests to assess their understanding of the causal status of the variables as well as the Control of Variables Strategy (CVS). Following this, in Phase 1.2, participants were provided a structured CVS training with probing questions that they answered together. To conclude this phase, parents and children explored the materials for 2-3 minutes while the experimenters were out of the room. In Phase 1.3, families engaged in a parent-child assessment in which they designed experiments to test one new and one previously discussed variable. In Phase 1.4, parents and children were given individual posttests in which they designed tests of two variables, and had their final conceptual knowledge of the causal status of the variables assessed. Phase 1.4 also included a far transfer measure of CVS understanding for both parents and children.

Table 2: Study design

	Phase 1	Phase 2	Phase 3	Phase 4
Session 1 (day 1)	1.1 Introduction to Task 1 & Individual parent and child pretests	1.2 Training (task 1, variables A & B) and brief parent-child self-directed exploration	1.3 Parent-child assessment (task 1, variables B & C)	1.4 Individual parent and child posttests
Session 2 (day 2, four weeks later)	2.1 Introduction to Task 2 & parent and child content pretests	2.2 Parent-child self-directed exploration (task 2)	2.3 Parent-child assessment (task 2, variables B & C)	2.4 Individual parent and child posttests

The second part of the study consisted of four phases that were parallel to Session 1. In Phase 2.1, parents and children were introduced to Task 2. They were shown how to use the materials and given brief pretests to assess their understanding of the causal status of the variables. In order to investigate the question of how parents facilitate transfer of prior knowledge, families engaged in self-directed exploration of the task in Phase 2.2. Families engaged in the second parent-child posttest activity in Phase 2.3, while in Phase 2.4 children and parents completed individual posttests and this phase also included a far transfer measure of CVS understanding. In addition to questioning parents and children about content and strategy knowledge, in this phase we inquired about activities during the four-week delay that parents and children engaged in together that involved joint scientific reasoning or informal experimentation activity.

The design of this study allowed for several levels of analyses that can describe the processes of joint scientific reasoning, but that also explore connections between those behaviors and outcome measures. In Phases 1.2, 1.3, 2.2, and 2.3, parents and children interacted together with two tasks. Parent-child conversation and behavior was observed in order to learn more about how parents support joint scientific reasoning both during self-directed exploration and during joint testing. Following the training and other activities in Session 1, parents and children had the opportunity to engage in self-directed exploration of Task 2 in Phase 2.2. This phase in particular, but along with Phase 2.3, addresses the question of how parents facilitate transfer of a scientific reasoning strategy. Parent and child talk and behavior in these phases were coded in order to explore various methods parents might use to activate prior knowledge and remind children of prior shared experiences.

In addition to exploring the processes of engaging in joint scientific reasoning, this design enables exploration of pre- and posttest measures in order to describe learning. The pre- and posttests establish children and parents' abilities to answer questions about CVS both individually before and after exploring the tasks and together following the exploration. CVS scores – on both the ability to design experiments and to explain the strategy – were also developed for both parents and children during the above phases based on the tests participants designed during pretest and the joint and individual posttests. The pre- and posttests also allowed for an exploration in changes in parent and child individual understanding of the causal status of task variables The pretests (1.1 and 2.1) provided a baseline of content knowledge about the variables in the Ramps and Springs tasks; following the engagement with the tasks, conceptual understanding was measured individually again the final phases of each Session (1.4 and 2.4).

Participants

Thirty parent-child dyads were recruited at the Pittsburgh Children's Museum. Approximately half of the children (n = 16) were in the younger group aged 5- to 6-years-old (*M* = 6 years, *SD* = 7 months) and the other half (n = 14) were in the older group aged 7- to 8-years-old (*M* = 7 years, 9 months, *SD* = 7 months). Each family completed the two sessions of the study, conducted one month apart (*M* = 31 days, *SD* = 7.7 days). In previous research, when children who worked alone on CVS tasks and were provided instruction and prompts, 8-year-olds did not make significant gains in use of the strategy beyond the initial learning context, however 9- and 10-year-olds were able to understand, learn, and transfer CVS when designing and evaluating simple tests (Chen & Klahr, 1999). The present study looked then at 5- to 8-year-olds and how their learning and performance could be enhanced with parent support in addition to training with prompting questions. The younger group was included because of our particular interest in the early development of scientific reasoning and how parents support this early development, even before children demonstrate much competency.

Our sample included 23 mothers and 7 fathers, 15 boys and 15 girls. There were 14 mother-son dyads, 9 mother-daughter dyads, 1 father-son dyad, and 6 father-daughter dyads. Participants were not selected with particular attempts to balance gender, as prior studies investigating similar scientific reasoning skills did not find gender differences (e.g., Chen & Klahr, 1999; Gleason & Schauble, 2000; Kuhn et al., 1988; Kuhn et al., 1995). However, we conducted preliminary analyses to explore gender effects; these analyses revealed no significant gender differences in CVS use in any phase or in content knowledge in either domain. Data were then combined across genders.

Several background measures were collected from families, such as educational level of parent(s), how often they engage in science activities alone or with children, whether they were members of the Children's Museum of Pittsburgh or other museums and how often they visit museums. Overall, 30% of families were members of the Children's Museum prior to the study and 60% were members of other museums in Pittsburgh. One-third of the participants visit museums once or twice each month, over half of the families visit museums once every 3 to 4 months, while 10% of families visit just once every 6 to 12 months. On average, parents reported engaging in science activities on their own and with their children between one and four times per month. However, more than 20% stated that they engaged in activities on their own and with their children more than one time per week. All children's parents had completed some college, while 80% had a bachelor's degree or graduate degree. Families were generally representative of Children's Museum of Pittsburgh visitors.

Rationale for No Control Condition

We engaged all families in the training in which the CVS strategy was made explicit through a training activity and probing questions and some of the variability of parent-child activity will be minimized. We predicted that the training would optimize parent support and that especially the older group would successfully learn the CVS strategy.

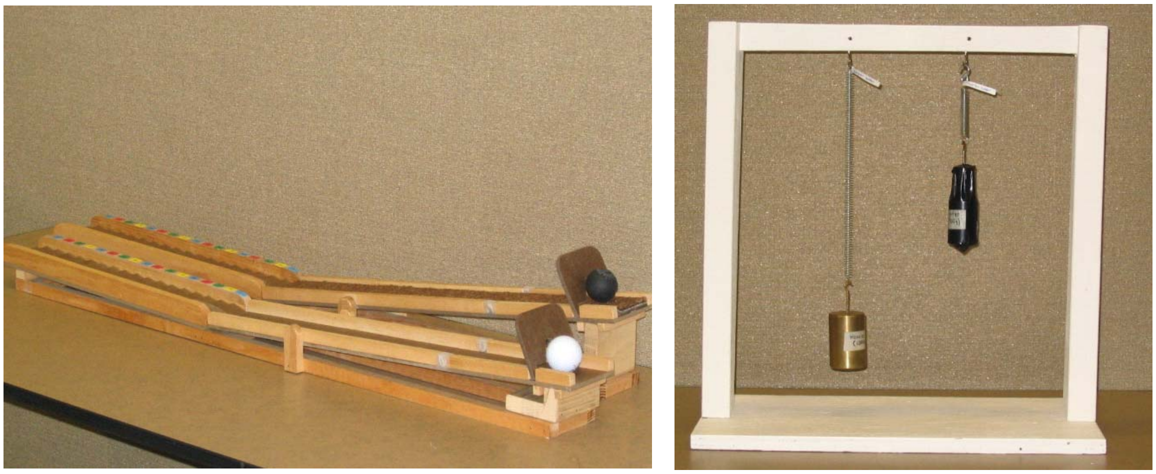
We had considered implementing a condition in which parents and children would be presented with the materials and asked to interact with them as they would typically explore an interactive museum exhibit. Rather than providing a structured training session, this would allow us to observe spontaneous activity to understand more about how parents and children discover together and later reference prior co-constructed knowledge. However, all children in the present study received the training for three main reasons. In prior research (Chen & Klahr, 1999), however, the youngest children (mean age 7 years, 10 months) were unable to transfer their learning beyond the setting in which it was learned (same domain with no time delay). If children of similar age with the oldest children in the present study demonstrated difficulty in learning, it would be unlikely that with less training children of similar age or younger would have success in learning CVS. Secondly, children who did not receive the full training (either received no training and no probing questions or only received probing questions) did not make significant improvements in their use of CVS. Only through exposure to training and probing questions did children learn CVS. Finally, we wanted to explore how parents and children talked about the strategy while designing tests and we thought it unlikely that many parent-child pairs would spontaneously engage in discussion of CVS while exploring these in the museum, especially with children aged 5- to 8-years-old. As demonstrated by Kim & Crowley (in preparation), parents were unlikely to explicitly discuss strategies for designing good experiments, even when parents were individually instructed about this prior to exploring the task with their children. For these reasons, all children in this study were provided training in the context of parent-child activity.

Materials

In both Ramp and Spring tasks, there were three variables that could assume either of two values. Parents and children explored both tasks to determine the causal status of each of the variables. In the Ramp task, the outcome was how far the ball would roll as a function of ramp surface, type of ball, and steepness of ramp. In the Spring task, the outcome was how far the springs stretch as a function of a spring length, coil width, and size of weight. Capital letters A, B, and C are used to refer to the three variables in both tasks throughout the methods section. This notation will make clear which variables are explored and tested in each phase. Families explored the Ramps during Session 1 and the Springs in Session 2.

Ramps Task

In the Ramps task, parents and children made comparisons to determine how the three variables affected the distance that the ball rolled after leaving a downhill ramp. Materials for this task were two wooden ramps, with adjustable downhill slide and a slightly uphill stepped surface on the other side (see Figure 1). Our ramps differed slightly from those in prior research (Chen & Klahr, 1999) as the length of run variable was eliminated. The slots that create a short length of run were filled in so that participants can only put the gates in the upper slots. Participants were able to set the steepness of the ramp (high or low) using wooden blocks that fit under the ramps in two orientations. Participants also were able to set the surface of the ramps (rough or smooth) by putting the inserts on the ramps either carpet side up or smooth wood side up. Additionally, participants could choose from two different types of balls, rubber squash balls or golf balls. To set up comparisons, participants constructed two ramps, setting the steepness, surface, and type of ball (one on each ramp). To execute the experiment, participants lifted the gates and watched to see how far each ball rolled up the stepped side of the ramp.



A B

Figure 1: Ramp (a) and Spring (b) materials used in Sessions 1 and 2

Springs task

In the Springs task, parents and children could make comparisons to determine the effects of three different variables on how far springs stretch. The materials (shown in Figure 1) consisted of four springs varying in length (longer and shorter) and coil width (wider and narrower); two of each type of spring were provided. Pairs of “heavier” and “lighter” weights, differing in shape so that they could easily be distinguished, were used in this task. To make comparisons, parents and children selected two springs to compare, hung them from hooks on a frame and selected a weight, which was then placed beneath the springs on the tabletop. To execute the comparison, participants hung the weights on the chosen springs to then observe how far down the springs stretched.

Procedure

The procedure involved two Sessions with four phases each, conducted one month apart. Table 3 provides an overview of the components in each phase.

Table 3: Component measures in each Phase of Sessions 1 and 2

Session	Domain	Phase	Components	Parent & child: separate	Parent & child: together
Session 1	Ramps	1.1	Introduction to task		
			Identify variables A, B, C		X
			Initial conceptual understanding	X	
			Produce two comparisons for each A and B	X	
			Justifications	X	
		1.2	Training on variables A and B		X
		1.3	Parent-child assessment		
			Produce two comparisons for each C and B		X
			Justifications		X
		1.4	Final assessment		
			Produce two comparisons for each C and B	X	
			Justifications	X	
			CVS transfer task	X	
			Final conceptual understanding	X	
Session 2	Springs	2.1	Introduction to task		
			Identify variables A, B, C		X
			Initial conceptual understanding	X	
		2.2	Self-directed exploration		X
		2.3	Parent-child assessment		
			Produce two comparisons for each C and B		X
			Justifications		X
		2.4	Final assessment		
			Produce two comparisons for each C and B	X	
			Justifications	X	
			Final conceptual understanding	X	
			CVS transfer task	X	
			Similarity questionnaire	X	

Session 1

The procedure for Session 1 was divided into four phases administered in a single session lasting approximately 45 minutes. All activities were videotaped for later coding and analysis.

Phase 1.1: Introduction to Ramps Task and Pretest

Parents and children were introduced to the Ramps task. The experimenter presented each of the three variables that could impact the outcome (steepness, ramp surface, and ball type). Following this brief familiarization phase, parents and children were interviewed individually. The interview then collected a baseline measure of children's beliefs about the causal status of the variables and knowledge of strategies for designing unconfounded experiments. Specifically, they were asked which of the two levels of each variable would have a greater impact on the outcome. For example, they were asked whether they thought the ball would travel farther after rolling on a smooth or rough surface. Then, children were asked to design two comparisons for each of two variables (A and B, where, for example, A = ramp steepness and B = type of ball). They then answered questions about their choice of comparisons and what they could tell from the outcomes.

The parent pretest interview addressed the same questions, after which parents were provided information about the following two phases. They were told that they were going to do an activity with their child and that they should assist the child in such a way that s/he would be able to complete the task on their own in the future.

Phase 1.2: Training

During training, parent-child dyads were led through the activity and provided explicit instruction about CVS. The experimenter provided parents and children with examples of both confounded and unconfounded experiments for variables A and B. Participants were asked to make judgments of whether the examples were good or bad comparisons and to provide their reasoning about why. Following their judgments, the experimenter provided an explanation of whether they were good tests and why.

Phase 1.3: Parent-child Assessment

Following exploration of the task and training, parents and children engaged in a joint posttest activity with the experimenter. During this phase, participants designed tests for variables C and B (one new and one old variable). They were asked to produce two comparisons and explain the reasoning behind their choice of objects. Following the execution of each experiment, the parent-child dyad was questioned about what they found and whether the comparison in question could inform them for sure about whether the variable made a difference.

Phase 1.4: Task 1 Final Assessment

Immediately following the parent-child assessment, participants were asked to individually by separate experimenters to design experiments to test variables C and B and had their final conceptual understanding for Task 1 variables assessed. Next, participants were given a "paper-and-pencil" posttest to examine their ability to transfer CVS to remote situations. The transfer questions were situated in two other domains in which CVS could be applied, such as building a fast toy racecar. Within these domains, participants were asked to evaluate example comparisons that were designed to test the effect of the target variable. As in Chen & Klahr (1999), the example comparisons were one of four types: unconfounded comparisons, comparisons with a single confound, comparisons in which every variable had different values, and non-contrastive comparisons in which the target variable did not differ. Within each domain, one comparison was an example of a good test (unconfounded), whereas the other two comparisons were chosen from the three types of bad tests.

As parents often finished this final assessment for Task 1 before children, the experimenter working with them asked questions concerning their museum habits, their child's interests and activities related to science, etc. To conclude Session 1, the experimenter(s) discussed scheduling options for Session 2 with the parent. Parents were given a flier with a reminder sticker with the target date to return for the second session. Often families scheduled their return visit at this time, otherwise they were told that they would be called or emailed to schedule a time to come back to the museum in the week surrounding the target date. Contact information was exchanged in order to confirm when the family would return to the museum.

Session 2

The second session was conducted approximately four weeks after Session 1. In order to explore how parents facilitate transfer of prior knowledge, we wanted to create a long enough delay so that families would be willing to return to the museum. Additionally, with our focus on parent support of transfer, we wanted to select a delay that would seem quite long to children, but not so long that parents would forget details of Session 1. Prior research with this task explored children's CVS use at a 1 week delay (Chen & Klahr, 1999); we wanted to increase this delay so that parent support might be more necessary.

Session 2 lasted approximately 35 to 40 minutes, depending partly upon how long families engaged with the task during the self-directed exploration in Phase 2.2. To complete the study, parents and children were contacted by the researcher to administer Session 2 in the museum. Upon completion of Session 2, parents and children were compensated for their participation in the study with their choice of a family museum membership or a gift certificate to the museum gift shop.

Phase 2.1: Introduction to Springs Task and Conceptual Pretest

Parents and children were shown the Spring task together to familiarize them with the variables in springs. They were then given brief individual conceptual understanding pretests. We did not include a CVS use pretest in this phase because we wanted parents and children to spontaneously use or not use this information in Phase 2.2. Asking them to design experiments in the new domain would have more explicitly remind them of the questions to ask themselves during the subsequent activity (e.g., Why did you set up the apparatus the way you did?; Can you tell for sure from this comparison whether [variable] makes a difference?).

Phase 2.2: Parent-child Self-directed Exploration of Task 2

Parents and children were asked to explore the Spring task to determine the causal status of three variables in the second domain. Participants were asked to engage with the task for approximately 10 minutes to allow them enough time to fully explore the task and make exposure to the second domain similar to the first. An informational activity sheet will be included with the task materials in order to help parents and children identify the variables and to remind them of the rules in using the interface (how to unhook the springs without launching them from the stand).

Phase 2.3: Parent-child Assessment

Following exploration of the task, parents and children engaged in a joint posttest activity with the experimenter. During the previous exploration, the families had the opportunity to explore all of variables, however in order to compare Session 2 results with Session 1, the questions during this phase addressed just two variables. Parents and children were asked to produce two comparisons for each variable and to explain the reasoning behind their designs.

Phase 2.4: Task 2 Final Assessment

The final phase of the study was similar to Phase 1.4; parents and children worked individually with different experimenters to design tests for the two variables used in Phase 2.3 and provide justifications. They then had the final conceptual posttest. Following these measures, the transfer task was again administered, in which participants again rated examples of experiments in two additional domains as “good tests” or “bad tests”. The study concluded with questions about participants’ interpretations of similarities between Tasks 1 and 2 in terms of CVS. Based on questions from prior work, participants were asked 1) if anything about the Session 2 task reminded them of the Session 1 task, 2) to explain how Tasks 1 and 2 were alike and/or different, and 3) whether they learned anything in Session 1 that helped them work on Task 2 and the transfer tasks (Chen & Klahr, 1999). Parents and children were also questioned about whether they engaged in any related scientific reasoning activities during the 4-week delay.

Coding and Analysis

To explore answers to Research Questions 1 and 2, three main coding passes were conducted. First, to address children’s learning, individual and joint pre- and posttest measures were created. Second, parent-child experimental activity was explored to describe how parents and children shared responsibility for the design and execution of experiments. Finally, codes were developed to describe the amount and kinds of talk that parents and children employed during the shared activities.

Pre- and Posttest Measures of Learning

From the data collected in the individual pre- and posttests of Phases 1.1, 1.4, 2.1, and 2.4 and the joint posttests of Phases 1.3 and 2.3, five major dependent variables were created: (1) *CVS* *use*: participants ability to use CVS to design unconfounded tests, (2) *Robust CVS use*: a more strict measure of participants' CVS understanding that required both the design of unconfounded experiments accompanied by verbal justifications to questions about why particular experiments were designed, (3) *content knowledge*, based on participants' responses to questions about the effects of different causal variables in each domain, (4) *Far transfer of CVS,* based on participants' judgments of good and bad tests of variables in the paper and pencil task and, (5) *Strategy similarity awareness*: based on participants' responses to questions about how the tasks were similar in terms of the underlying strategy used to design experiments.

The experimenters recorded participants' design of experiments during testing using an interview-coding sheet, and this information was double checked for accuracy from videotape. CVS use was assessed by participants' selection of valid of comparisons – the design of unconfounded, contrastive experiments of the target variable. Additionally, the longer free-response answers to questions in which participants provided justifications for their choices were transcribed from video and then coded from transcript. Robust CVS use was determined from the design of participants' tests along with their justifications. Based on the coding of Chen and Klahr (1999), justifications for the design of comparisons were coded as one of the four following categories: 1, justifications that mention CVS by identifying the variable that is different and the two variables that are the same, 2, justifications that mention controlling the target variable and one of the two other variables, 3, justifications that mention controlling only the target variable, and 4, explanations that did not refer to CVS. When participants provided category 1 justifications, they were assigned a score of 1, while the other three types of justifications were assigned a score of 0.

From the joint posttests, parents and children's collaborative CVS and Robust CVS scores were also computed. Again, the experimenters recorded participants' joint design of experiments during testing using an interview-coding sheet, and this information was double checked from videotape for accuracy. Again, CVS use was assessed by participants' selection of valid of comparisons and Robust CVS use was determined from the design of participants' tests along with their justifications and was coded from the parent-child joint posttest transcript. The Robust CVS reasons were also coded by a pair of coders for whether the reasons were provided by a parent alone, a child alone, or by the parent and child jointly.

Conceptual understanding was assessed by asking participants how they thought each variable would impact the outcome in pre- and posttests. Participants' correct judgments were assigned a score of 1, whereas incorrect judgments were assigned a score of 0.

Parent-child Experimental Activity

Parent-child activity was coded for general experimentation activity, such as length of exploration and the number and type of experiments run. Additionally, parent-child activity was coded for who Executed the experiments and who Designed the experiments. These codes describe whether the Design or Execution was completed by a parent alone, a child alone, or through joint parent-child activity. In the Execution of experiments, if both the parent and child physically placed at least one level of one variable, the Execution was joint, otherwise it was either individual child or parent. During the Design of the tests, if both the parent and the child determined at least one level of one variable, the Design was classified as joint. The Design was joint even if one participant determined the levels of the first variable, and the other participant actually designed the test as being unconfounded following the determination of the levels of the first variable.

Parent-child Talk during Self-directed Explorations and Joint Posttests

Parent-child conversations during exploration of Tasks 1 and 2 were coded to explore the processes of joint scientific reasoning. Phases 1.2, 1.3, 2.2, and 2.3 involved videotaped parent-child interactions during exploration of the tasks and joint posttests. The talk and actions of parents and children were first transcribed and then coded by individual coders from transcripts. All transcripts were double-checked prior to coding.

The coding scheme was developed by building on an existing coding scheme that was used for coding spontaneous family interactions with museum exhibits (Crowley & Callanan, 1998; Crowley, Callanan, Tenenbaum et al., 2001; Crowley, Callanan, Jipson et al., 2001). Furthermore, I was interested in exploring how parents and children share responsibility for the design of experiments and evaluation of evidence. Therefore, codes were developed to capture the various kinds of talk that parents and children engaged in that served to support Planning and Evaluating activity. The conversation codes developed for this study are listed below with their definitions. Additionally, several codes were developed that were not able to be cleanly grouped into Planning or Evaluating phases, but were used to describe additional types of conversation that related to experimental activity in which we were interested.

Planning:

- Remind about strategy – general or specific references to CVS, including comments (e.g., We need only one thing different or How many things different can we have?)
- Label variables – identifying one or more levels of one or more of the variables of which a participant in currently manipulating (e.g., This is a longer, wider spring.)

- Variable level check – talk that confirms the level of a variable, often checking on the design of the current test (e.g., Are those the long wide ones? or Did you make them both high (steepness)?)
- Establish goals, general – Talk suggesting or asking about how to proceed generally with experimentation (e.g., What do you want to test next? How do you want to test that?)
- Establish goals, specific – Talk suggesting a specific next step in experimentation (e.g., Let's test to see if steepness makes a difference or Let's try the long springs next time)
- Assign roles – talk that establishes that either the parent or child execute a particular action (e.g., You hang the weights, or I'll build this ramp; you can build that one.)

Evaluating:

- Describe evidence – talk that directs attention to available evidence, describing what is seen (e.g., That rolled really far, or That didn't stretch hardly at all)
- Interpret evidence – talk about evidence that moves beyond description, adding an interpretive layer (e.g., That didn't go as far this time; this must be a slower ramp)
- Replication of test – talk about repeating a particular test due to error or another reason (e.g., Maybe we should do that one again; it bumped off the side)
- Replication of variable – talk about confirming the causal status of a variable by testing it with another type of experiment (e.g., Let's test it with the lighter weights and see if the longer ones still go farther.)

- Variable effect – talk that states the causal status of a variable (e.g., So the longer wider ones go down farther than the shorter wider ones with the light weights, or Steep ones make the ball go farther.)
- Isolate variables – talk that states the causal status of a variable, often following a statement of variables' effects that combines more than one variable. The isolating variable comment focuses on one variable's effect and specifically removes or isolates the effect of that variable from the others (e.g., C: The Longer Wider really stretches far down with the lighter weights! P: <u>So, the Wider ones stretch farther</u>.)

Other categories of talk:

- General Experimentation Questions – questions asked that are about experimentation that were not coded as more specific categories
- Make predictions – talk that discusses or questions the result of an experiment prior to executing the experiment (e.g., which one do you think will go farther?)
- Consider hypotheses – talk that asks about or comments on why a particular variable has a particular effect (e.g., Why do you think the wider one stretches longer? or So maybe the longer ones stretch farther down because there is more of them.)
- Reference previous visit – talk during Session 2 that references the first part of the study (e.g., Remember when we were here last time, what we learned?)
- Mention ramps – talk during Session 2 that explicitly refers to the ramps activity (e.g., I bet you thought we were going to be using the ramps today.)

Due to the nature of the joint posttest, where participants were responding to particular questions from the experimenter about the design and outcome of experiments, additional codes were added or modified to better describe the Planning activity that took place during the posttest. In particular, the Reference Strategy code described above was broken down into the following more specific codes:

- RS (general) – general reference strategy (e.g., Remember the rule?, or How many things do we have different?)
- RS(1) – talk referencing one variable (e.g., Because we are seeing if weight makes a difference, so weights are different)
- RS(2) – talk referencing two variables – (e.g., this is the same, and this is different (leaves out 1 variable))
- RS(3) – talk referencing 3 variables, similar to Robust CVS use – (e.g., this (weight) is different; everything else the same. In the Spring domain comments qualify for RS(3) if for testing weight, springs are the same, weights are different" – because the springs being the same (could possibly work for testing type of ball in ramps if they say "the ramps (or everything about the ramps) are same and the balls are different)

Indirect or implicit references to the strategy in talking about the design of experiments:

- "has to be" – talk stating a variable needs to assume, or "has to be", a particular level (e.g., Following making one Ramp high when asked how to build the second ramp, the child replies "It has to be high")

- “Both: – talk that states both variable need to be the same level, typically using the words “both” or “same” (e.g., How should make the steepness? <u>Height is the same</u> or Both are high.)

Additionally, another code, “Test” was created to categorize talk about the specific goal in designing an experiment. Test talk helped to remind about the particular goal of an experiment or was talk used to describe the reason behind the design of an experiment (e.g., What are we testing? Ramp surface, remember…so that needs to be different, or We made them that way because we are testing type of ball.) Finally, parent talk which provided praise was more common in the posttest situation, therefore a “Praise” code was added for coding of the posttest transcripts.

All Ramp and Spring self-directed explorations were coded first, followed by the Ramp and Spring posttests. This coding was completed from transcripts, which had been double-checked for accuracy of talk and action.

Reliability

Reliability coding was performed on two main sections of coding: 1) the talk and activity that was coded into Design and Execution of experiments and 2) the talk that was coded and then categorized into Planning and Evaluating talk. In the self-directed explorations of Ramps and Springs, reliability was 87% and 81% for determination of Execution and Design, respectively. In the posttests, reliability was 93% and 85% for determination of Execution and Design, respectively. For Planning and Evaluating talk in self-directed explorations and posttests, the reliability was 75% and 83% respectively.

CHAPTER 4

RESULTS

The first two sections of the results are organized around the two main research questions of this dissertation: 1) Can children learn and transfer a scientific reasoning strategy when provided training situated within parent-child activity? and 2) How do parents support learning and transfer in joint scientific reasoning activities? The third section of the results explores associations between parent support and children's learning and transfer of the strategy.

Children's Learning and Transfer of the Control of Variables Strategy

Children's use of the Control of Variables Strategy will be explored across the five test phases of the procedure. Children were asked to design experiments during the Ramps procedure on their own during the individual pretest, with parents during the joint posttest, and on their own again during individual posttest. During the Spring procedure, approximately one month later, children were asked to design experiments with parents during the joint posttest and then alone during the individual posttest. This exploration of CVS across time demonstrates children's abilities to design tests as well as their exposure to use of the strategy with parents.

Children's use of CVS in Individual and Joint Measures

Children's ability to use CVS was first measured in the individual pretest. As seen in Figure 2, both younger and older children were unlikely to successfully use the strategy, with only about one-fifth of all trials involving unconfounded tests. In contrast, use of CVS was almost 100% on the joint posttest. We had expected there to be fairly high levels in the joint-posttest, because we expected that the parents were likely to be expert users of CVS at the end of the training. However, what was of more interest was the first individual posttest, where children generally maintained high levels of CVS. Thus, it appeared that many older and younger children learned how to use the CVS strategy on their own.

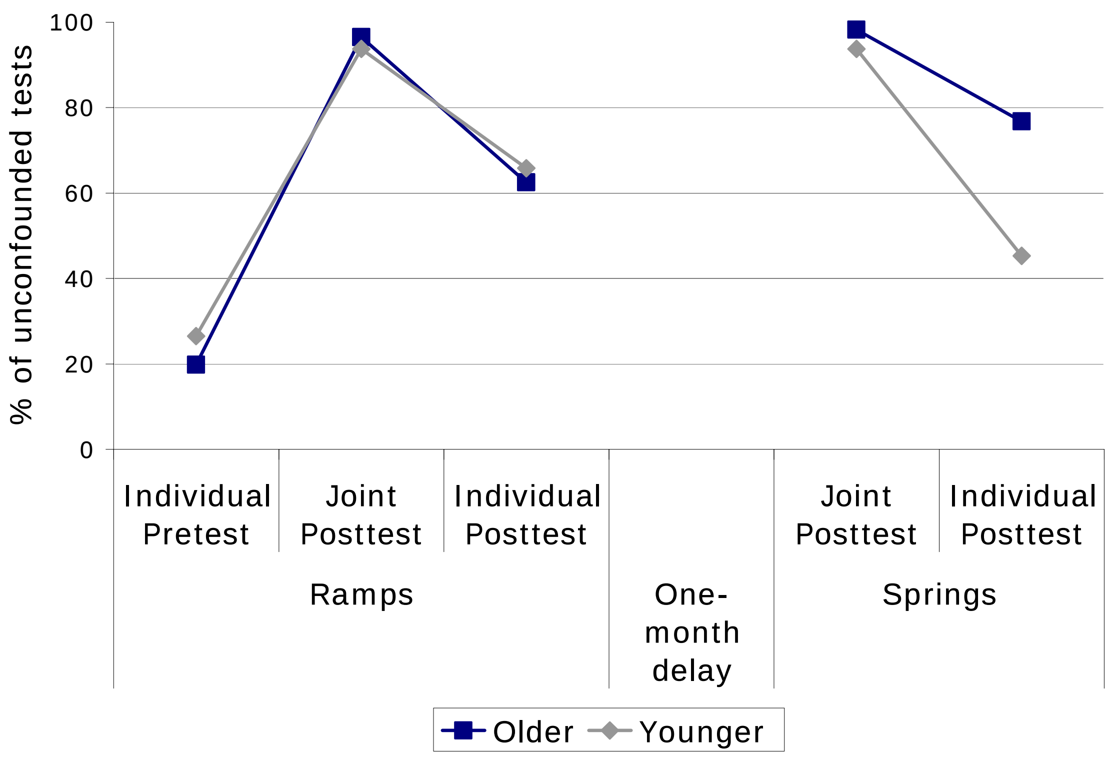


Figure 2: Use of the Control of Variables Strategy by older and younger children

Following the one-month delay, families returned to participate in a self-directed exploration of the Springs tasks. On the joint posttest that followed the task, parents and children were once again close to ceiling on CVS use. It was on the subsequent individual posttest where we first encountered the suggestion of age-related differences. Older children continued to improve over their Session 1 individual performance, averaging 77% unconfounded tests.

Younger children's performance, however, did not continue to improve. Despite designing primarily unconfounded tests with parents in the joint posttest, younger children only averaged 45% unconfounded tests on the individual posttest.

To explore whether changes in children's use of CVS were statistically significant, a 3 (phase) x 2 (age group) repeated-measures ANOVA was performed with children's CVS use in the individual pretest, first individual posttest, and second individual posttest as a within-subjects variable. Analyses confirmed the patterns suggested in Figure 2. There was a significant main effect for phase, $F(2,27) = 24.71$, $p < .001$, indicating children generally learned the CVS strategy, and a significant phase-age group interaction, $F(2,27) = 5.14$, $p<.05$, suggesting that older children continued to improve from the first to second posttest while younger children did not.

A follow-up one-way ANOVA on older children's CVS use revealed a significant effect for phase, $F(2,12) = 20.80$, $p < .001$, with paired comparisons confirming that they performed better in both posttest phases than in pretest, ps < .001. The improvement between the first and second individual posttest was marginally significant, $p = .10$.

A follow-up one-way ANOVA on younger children's CVS use also revealed a significant effect for phase, $F(2,14) = 8.81$, $p < .01$, with paired comparisons suggesting that younger children significantly improved in their use of CVS between Pretest and Posttest 1, $p = .001$. Unlike older children, whose performance continued to improve, younger children's performance significantly decreased between Posttest 1 and Posttest 2, $p < .05$, suggesting it was more difficult for younger children to transfer the strategy. However, despite this decline in use of CVS, younger children's Posttest 2 performance remained significantly improved over pretest, $p < .05$.

Children's Robust CVS Use in Individual and Joint Measures

Children were asked, following the design of each test, to explain why they constructed the comparisons the way they did. As shown in Figure 3, children were not likely to provide a CVS reason in pretest (only 1 older and 1 younger child did so). Although we saw in Figure 2 that parent-child dyads were likely to design unconfounded tests on the first joint posttest, Figure 3 shows that they were much less likely to give CVS reasons, particularly with the younger children. When tested individually, Robust CVS for both older and younger children dropped off, although still remaining above pretest levels. Similar differences in joint and individual posttests were seen in the second session, with about half of the trials showing Robust CVS use on the joint posttest before dropping off again on the individual posttest.

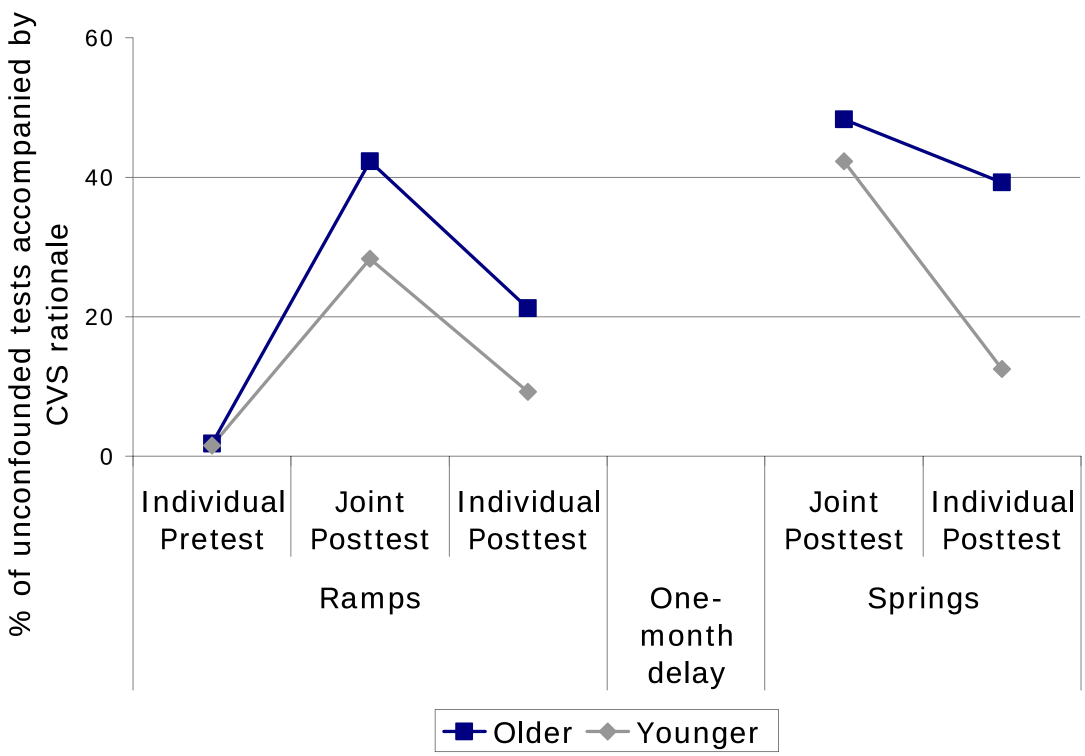


Figure 3: Robust CVS use by older and younger children

A 3 (phase) x 2 (age group) repeated-measures ANOVA was performed with Robust CVS use on the pretest, first individual posttest, and second individual posttest as a within-subjects variable. The analyses revealed a significant main effect for phase, $F(2, 27) = 8.96$, $p < .01$, indicating that children were increasingly able to provide CVS explanations across phase. There was also a significant effect for age group, $F(1, 28) = 4.71$, $p < .05$, with older children being more likely to be Robust CVS users. The interaction of phase and age was not significant, $F(2, 27) = 2.32$, n.s.

For older children, a follow-up one-way ANOVA on Robust CVS use across the pretest and two individual posttests revealed significant improvement, $F(2,12) = 7.83$, $p < .01$, with paired comparisons suggesting that older children's Robust CVS use in both posttests was significantly greater than in pretest, ps < .01. Although older children's Robust CVS use nearly doubled from Posttest 1 to 2, the difference was not significant ($p = .12$). A one-way ANOVA on younger children's CVS use across phase, however, did not demonstrate a significant improvement $F(2,14) = 1.59$, n.s. Paired comparisons revealed that even the largest difference, from Pretest to Posttest 2 was not significant ($p = .13$).

Children's ability to explain the strategy while designing unconfounded experiments (Robust CVS) did not approach the level of their ability to simply design unconfounded experiments (CVS use). This could be due in part to their exposure to CVS use and Robust CVS use with parents; whereas parents modeled joint CVS use at a very high level, this was not true for Robust CVS use. During the joint posttests, parent-child dyads designed nearly 100% unconfounded experiments, however, joint Robust CVS use never reached 50%. Parents did not provide a high level Robust CVS independently or prompt children to do so, and this was even more true for interactions with younger children. Children often explained the design of their tests by providing the goal behind the experimental design ("I designed it that way to see if type of ball makes a difference") or by focusing on the target variable ("I needed to choose different types of balls"). As these are sensible and good answers to the experimenter's questions, parents, especially with younger children, did not prompt children to go further in their explanations, or elaborate on children's answers themselves. Therefore, if parents did not frequently model Robust CVS use by addressing the levels of all variables in the tasks or posttests with children, even children who knew and used the strategy would be unlikely to do so.

Additional Measures of Children's Learning

I conclude this section of the results by exploring four additional individual measures of children's learning: 1) individual paths children followed to learn the CVS strategy; 2) children's understanding of the three causal variables in each task; 3) children's performance on the paper-and-pencil far transfer task; and 4) children's awareness of the underlying similarity of using the CVS strategy across activities.

Paths to CVS Learning: Identifying Good and Poor Experimenters

The aggregate individual posttest data in Figure 2 suggests that children could learn and transfer the CVS strategy. In Figure 4, I trace the path of this learning by breaking the children into four subgroups based on their performance on the two individual posttests. A child was determined to possess the CVS strategy if it was used on 3 of the 4 trials during an individual posttest. There are four potential paths, defined by whether or not a child possessed the CVS strategy on the Ramps individual posttest and/or the Spring individual posttest.

As shown in Figure 4, 10 children followed Path 4, never meeting the criteria of having learned CVS in either Sessions 1 or 2 (R-S-). Of the other 20 participants, 11 children followed Path 1 in that they knew and used CVS in both Session 1 and 2 (R+S+). Nine children followed the middle two paths, in which they knew the strategy in one session, but not the other: Six of these children knew and used CVS in the first session but failed to transfer in the second session (R+S), while and three children learned CVS for the first time during the second session (R-S+).

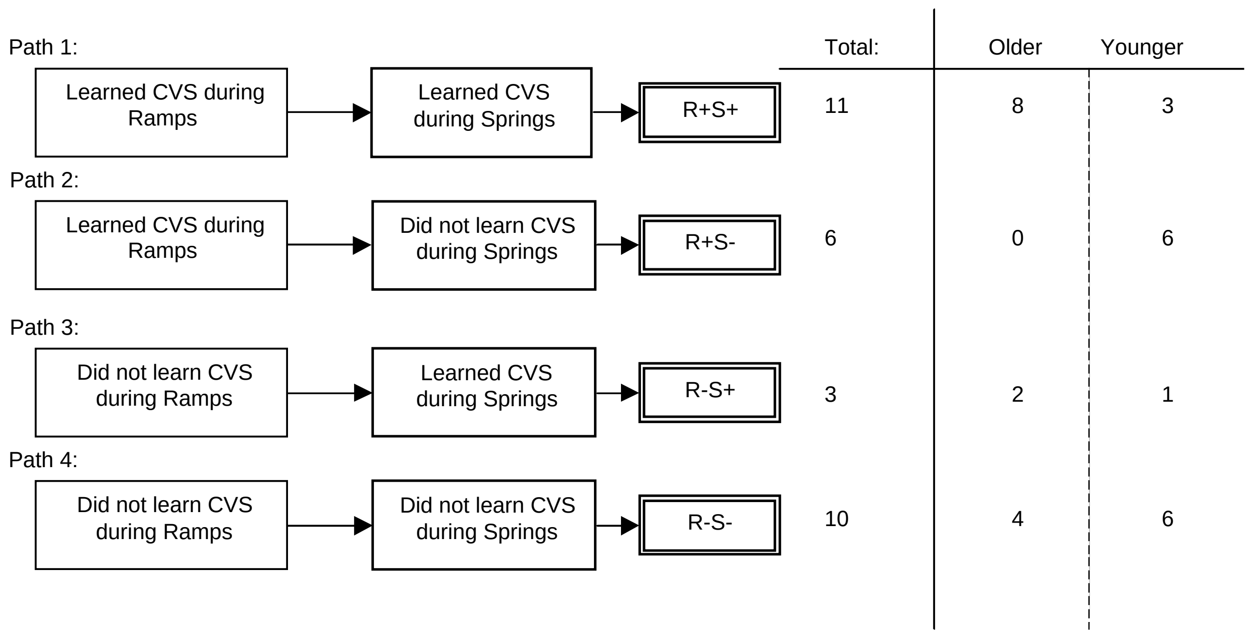


Figure 4: Older and young children following four possible learning paths

These paths confirm the earlier indications of age-related differences in learning. Specifically, note that all of the eight older children who learned the strategy during the first session were successful in transferring that learning to the second session. This is in contrast to the younger children, who actually had more CVS learners in the first session than the older children, but who saw only three of the nine learners transfer the strategy to the second session. If children did not learn CVS during the first session, they were unlikely to learn it in the second session, with only three of the thirteen non-learning children in the first session going on to learn CVS in the second.

In addition to describing differences in how children learned and transferred CVS, the paths can also be used to roughly divide the sample into the top and bottom thirds in terms of

CVS use. From this point forward, the group who learned and transferred the strategy (R+S+) will be called the Good Experimenters while the group who failed to learn (R-S-) will be called the Poor Experimenters. Subsequent analyses will often draw comparisons between these two groups in an effort to begin uncovering some of the processes underlying the ways that children learned and used CVS.

Understanding of the Effects of the Variables

Although the study focuses mostly on children learning the CVS strategy, the ability to design and interpret unconfounded experiments is ultimately important because it enables children to make valid inferences about the effects of variables. Children knew a fair amount about the domain variables prior to engaging in the activities. As seen in Figure 5a, children averaged 2.4 variables correct out of 3 variables in the Ramp domain in pretest, and 2.1 variables correct in the Spring domain. By posttest, both older and younger children made significant improvement in their understanding of the variables in both domains, improving their average to 2.9 correct in Ramps and 2.8 in Springs, Ramps: $F(1, 20) = 10.11$, $p < .01$; Springs: $F(1, 26) = 44.44$, $p < .001$. There was no main effect for age.

Figure 5: Content learning of (a) older and younger children in Ramp and Spring Domains and (b) Good and Poor Experimenters

Children learned about variables in the context of using the Ramps and Springs with their parents. As we have already seen (Figure 2, e.g.), most of the parent-child designs were valid comparisons. Thus, both the Good and Poor Experimenters would have had opportunity to make valid inferences and learn about the variables. A 2 (learning group) x 2 (phase) repeated-measures ANOVA on children's pre- and posttest knowledge of the six total variables from the two domains did find a significant main effect for phase, $F(1, 13) = 16.18$, $p = .001$, with both Good and Poor Experimenters improving from pre- to posttest (Figure 5b). However, the ANOVA also revealed a marginally significant effect for learning group, $F(1, 13) = 4.30$, $p = .058$, indicating that Good Experimenters had a marginally better understanding of the content variables overall. The interaction of learning group and phase was not significant; reasons for the similar learning gains of Good and Poor Experimenters will be presented in the discussion.

Far Transfer of CVS

At the conclusion of each session, children completed a paper and pencil far transfer test with the experimenter. The main dependent measure was the number of correct responses to 6 questions in each of the two tests. As seen in Figure 6a, a 2 (session) x 2 (age group) repeated-measures ANOVA with phase as a within-subjects variable revealed a significant main effect for session, $F(1, 28) = 7.17$, $p < .05$, suggesting that children's ability to transfer the strategy to a new task improved with experience using the strategy. There was no main effect for age, $F(1, 28) = 0.24$, n.s. The interaction of phase and age group was not significant, $F(1, 28) = .50$, n.s.

To explore the transfer abilities of the Good and Poor Experimenters, a 2 (age group) x 2 (learning group) ANOVA was performed on the total number correct from both transfer tasks. As shown in Figure 6b, there was a significant phase-age group interaction, $F(1,20) = 5.21$, $p <$

.05, suggesting that older and younger children in the Good and Poor Experimenter groups had different patterns of transfer. There was a significant main effect for learning group, $F(1,20) = 19.53$, $p<.001$, indicating that overall children who were able to use CVS in designing experiments were better able to transfer the strategy to new domains and tasks. There was also a marginally significant effect for age group, $F(1,20) = 3.80$, $p=.068$, indicating that younger children performed slightly better on the transfer task. Although not many younger children successfully used CVS in both Sessions 1 and 2 (i.e., were Good Experimenters), those children who did so performed extremely well on the transfer task.

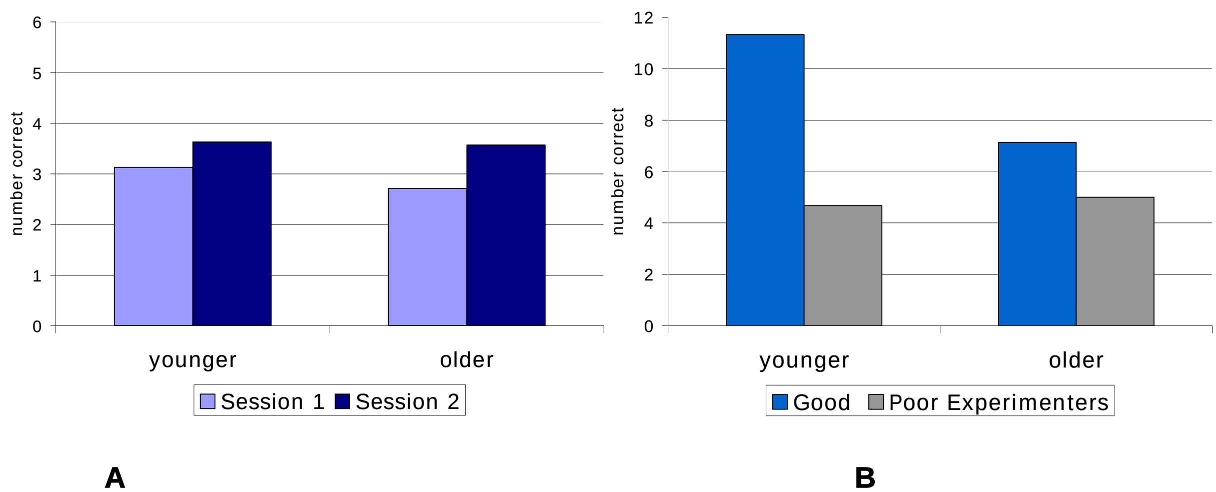


Figure 6: Transfer task performance of older and younger children in (a) Sessions 1 and 2, and (b) for Good and Poor Experimenters

Strategy Similarity Awareness

At the conclusion of the procedure, children were asked questions to reveal their interpretation of similarities across tasks in terms of CVS. About two-thirds of children said that Session 2 reminded them of Session 1, but they were unable to reference making experiments or the strategy (“having one thing different”) as the reason. When asked if the activities were mostly alike or mostly different, only six children stated the two activities were mostly alike. Even when prompted to think of reasons the activities were alike, only two children cited the strategy or the design of good experiments as the reason they were alike. This questionnaire reveals that even when children transferred the strategy in the context of designing experiments, it was hard for them to go beyond surface features (one uses balls, the other uses springs) to explicitly make abstract connections in discussing the activity.

Comparing the performance of Good and Poor Experimenters in the Strategy Similarity questionnaire revealed few differences. However, when asked if the activity in Session 2 reminded children of the activity they did in Session 1, Good Experimenters (67%) were more likely than Poor Experimenters (0) to either at least generally reference the making of comparisons or reference CVS specifically as the reason the Spring activity reminded them of the Ramp activity, χ^2 (1, N = 13) = 6.74, p < .01. Also, in asking children what would be really important to tell a younger child if they wanted to help a him/her to make fair tests, Good Experimenters (46%) were marginally more likely than Poor Experimenters (10%) to say they would tell the littler child to design experiments with only one difference, χ^2 (1, N = 21) = 3.23, p = .07.

Parent Support of Children's Learning and Transfer

This section examines how parents supported children's learning and transfer and whether there were any age-related differences in the kinds and level of support that parents provided. I begin with a brief overview of parents' own knowledge about the CVS strategy and the task, as revealed by their individual pre- and posttest performance. These results will establish that parents were knowledgeable enough to offer effective support. I then present an analysis of the extent to which parents and children shared responsibility for designing and executing experiments during self-directed exploration and joint posttests. These findings bear most directly on questions of how parents scaffold children's activity. Finally, I present description of parent-child talk during the self-directed exploration and the joint posttest. These findings elaborate specific ways that talk functioned in interactions with older and younger children.

Measures of Parent Knowledge

Parents in general were knowledgeable about the Control of Variables Strategy and were able to use this knowledge across the various learning measures. This section will briefly address parent knowledge and changes in performance over time.

Parent Use of Control of Variables Strategy

CVS use. Overall, parents knew and used the strategy throughout the procedure. Parents began the procedure by primarily using the CVS strategy in the design of their experiments; 91% of the pretest experiments parents designed were unconfounded. In Sessions 1 and 2 respectively, 100% and 98% of parents' experiments were unconfounded. As parents were near ceiling, it was not surprising that a repeated-measures ANOVA with phase as a within-subjects variable did not reveal a significant effect, $F(2,25) = 2.54$ $p = .10$. However, paired comparisons suggested CVS use in Posttest 1 was significantly greater than in pretest, $p < .05$ and the somewhat elevated CVS use in Posttest 2 over pretest levels was marginally significant, $p = .058$. Posttests 1 and 2 were not significantly different from each other.

Robust CVS use. Parents provided an explicit CVS rational for 44% of unconfounded experiments designed in pretest, 70% in Posttest 1 and 78% in Posttest 2. An ANOVA with phase as a repeated measure revealed a significant effect for phase, $F(2, 28) = 19.23$, $p < .001$, with comparisons showing that parents were more likely to provide a CVS reason in both

Posttests 1 and 2 than in pretest. Although parents knew the strategy coming into the activity, it was not until after they were provided training that they understood what the experimenter expected as the right answer and how to provide that. It is interesting to note that even when knowing the strategy and being able to provide Robust CVS responses, parents only provided such responses on three-quarters of trials. This may be important in considering what levels of correct responses experimenters would expect from children.

Understanding of the Effects of the Variables

Parents also knew a fair amount about the domain variables prior to engaging in the activities, averaging 5 of the 6 total variables from the two domains correct in pretest. By posttest, parents showed a significant increase in their understanding of the variables, improving their average to 5.9 of 6 variables correct, $F(1, 24) = 32.06$, $p < .001$.

Far Transfer of CVS

Parents had little trouble using the CVS strategy on the paper and pencil transfer tasks at the conclusion of Sessions 1 (98% correct) and 2 (97%).

Strategy Similarity Awareness

Parents were asked questions designed to elicit their interpretation of similarities across tasks in terms of CVS and to elicit their opinion of their child's understanding of the similarity. Nearly every parent said that the activity in Session 2 reminded them of the activity in Session 1, and 30% explicitly cited the Control of Variables Strategy as the reason (e.g., that they were trying to find out things by making everything the same except the thing they were trying to find out about). Nearly half of the parents (43%) did not explicitly cite the strategy as the reason, but stated the activities were alike because they involved making comparisons. When asked if parents believed their child viewed the activities as being similar, half reported they believed their child saw them as being similar. Forty percent of parents said they reminded children generally of what they learned the previous week, and 8 of these parents said that they explicitly reminded them of the strategy.

Although there were no differences in how parents of Good and Poor Experimenters reported strategy similarity between the two Session activities, parents of Good Experimenters (73%) were more likely than parents of Poor Experimenters (30%) to report that their children viewed the activities as being similar, χ^2 (1, N = 21) = 3.83, p = .05. This is one indication that parents were aware of their children's knowledge and perception of the tasks.

Summary

These various measures of parent knowledge indicate they had a good understanding of the strategy and that they were able to state the strategy rationale. This information is useful as we move forward to discuss parent-child activity and conversation; from these individual measures of parent knowledge, we know that parents had sufficient knowledge of the strategy to support children's learning.

Parent-child Experimentation

Parents and children engaged in design and execution of experiments during the self-directed exploration of Ramp and Spring domains as well as during the joint posttests. Results related to the design and execution of experiments are presented in the next two sections.

Parent-child Experimentation during Self-directed Exploration

Parents and children were asked to explore the materials and design experiments using each task prior to the joint posttests. In Session 1, parents and children were given about three minutes to explore the ramps with the experimenter out of the room. Parent-child dyads designed between one and eight experiments, with older child groups designing about one more experiment (M=4.0) than younger child groups (2.7).

In Session 2, parents and children were asked to explore the Spring materials for about 10 minutes and to tell the experimenters when they were finished. Dyads with older and younger children had similar experiences exploring the Springs in terms of length of exploration and number of experiments designed. Parent-child dyads with older and younger children averaged 10 min, 31 sec and 10 min, 45 sec, respectively. The number of experiments ranged from five to 23, however, there was no difference in the number of experiments designed by dyads with older (12.4) or younger (10.3) children, $F(1, 29) = 1.55$, n.s.

Table 4 summarizes parent-child experimentation during self-directed experimentation. Parent-child talk and actions were coded for whether the parent alone made all decisions about the design of each test, whether child made the decisions, or whether they jointly contributed to the design and execution of the tests. The table breaks down the Design category into unconfounded experiments and "other types" of experiments. In the other types category are experiments that were confounded and non-contrastive. Although parents and children did not intend to design "bad" tests for some of their experiments, they did sometimes intentionally design non-contrastive tests in order to check that the experimental materials were equal and they sometimes designed confounded tests to determine whether a particular variable had more influence on the result. The discussion here focuses primarily on the design of unconfounded tests, however. The distribution of roles in the design of unconfounded experiments was more evenly distributed between the three categories than were the roles in the execution of experiments. Parents and children worked together to design experiments, collaborating approximately twice as often in creating good experiments in the Springs domain as in the

Ramps domain, however this difference was not significant, $F(1, 29) = 2.43$, $p = .13$. In looking at the number of tests designed by older and younger children, a 2 (phase) x 2 (age group) repeated-measures ANOVA revealed a marginally significant interaction, $F(1, 29) = 3.47$, $p = .07$. Younger children designed slightly more unconfounded tests on their own in the Ramp domain, while older children designed more unconfounded tests on their own in the Springs domain. This finding could be partially attributed to the lower proportion of unconfounded tests designed in Ramps by dyads with older children (only 62%), and therefore a fewer number of tests overall included in the analysis.

Parents and children often collaborated on the execution of experiments, with a little more than half of the experiments being executed jointly. As shown in Table 4, children on their own executed the majority of remaining experiments, with parents occasionally executing a trial on their own. The overall distribution of the role of executing experiments was similar in the Ramp and Spring domains.

Table 4: Percentage of dyads that had parents alone, children alone, or joint execution or design of unconfounded experiments during parent-child self-directed experimentation

				Design of Unconfounded Experiments by:			**Design** of Other Types of Experiments by:			**Execution** of experiments by:		
		Number of exp.	Percent Unconf.	Parent	Child	Both	Parent	Child	Both	Parent	Child	Both
Ramp	Younger	2.7	.75	.20	.38	.17	.03	.12	.10	.08	.39	.53
	Older	4	.62	.25	.22	.16	.12	.21	.05	.21	.28	.52
Spring	Younger	10.3	.82	.32	.20	.30	.05	.10	.03	.08	.41	.52
	Older	12.4	.76	.22	.31	.23	.10	.09	.05	.09	.42	.48

This data indicates that parents and children shared responsibility during the self-directed exploration of the Ramps and Springs. The majority of their experiments were unconfounded and children alone designed between 20% and 38% of the unconfounded experiments. The distribution of responsibility in the design of experiments may have supported children's learning in that they had generally equal opportunities to observe parents designing tests, to work with parents to design tests, and to construct tests on their own. As seen in previous research (e.g., Gleason & Schauble, 2000), parents did not dominate the manipulation of the materials, leaving much of that activity to children; children alone were responsible for executing the tests for between 28 and 42% of trials, while parents and children collaborated in approximately half of the tests.

Parent-child Experimentation during Joint Posttest

Parents and children were asked to design four experiments together in each joint posttest. Parent-child talk was again coded for whether the parent alone was responsible for the design and execution of each test, whether child made the decisions, or whether they jointly contributed to the design and execution of the test. As seen in Table 5, the percentage of trials in which parents made all decisions was fairly low (overall average of 11% of trials in Ramps and 10% of trials in Springs). In briefly exploring the design of "other types" of experiments, we observe that parents alone and older children alone did not design confounded or non-contrastive tests. Although overall infrequent, the design of other types of tests was attributed to younger children alone or to parents and children jointly.

Table 5: Percentage of dyads that had parents alone, children alone, or joint execution or design of unconfounded experiments during joint posttest

		Design of Unconfounded Experiments by:			**Design** of Other Types of Experiments by:			**Execution** of experiments by:		
		Parent	Child	Both	Parent	Child	Both	Parent	Child	Both
Ramps	younger	.19	.46	.32	0	.03	.01	0	.56	.44
	older	.02	.43	.53	0	0	.02	0	.36	.64
Springs	younger	.11	.29	.50	0	.07	.03	0	.43	.57
	older	.09	.45	.43	0	0	.04	0	.55	.45

A 2 (phase) x 2 (age group) repeated-measures ANOVA on the number of collaboratively designed trials revealed a significant phase-age group interaction, $F(1, 28) = 6.00$, $p < .05$. During the design of ramp experiments, parents collaborated more with older children, while during the Spring joint posttest, parents collaborated more with younger children. The proportion of collaborative designs is obviously related to how often parents or children designed tests on their own. Overall, because parents may have viewed this as a testing session for their children in which they were assisting, parent solo designs were not frequent. Due to the particularly low parent solo design with older children in Ramps, the proportion of collaborative and child solo designs were higher. During the Spring joint posttest, the number of younger child solo designs were lower, again leaving more experiments to be collaboratively designed. Additionally these numbers illustrate that even though parents were there to step in to assist children in getting the right answer during posttest, both older and younger children were in fact able to design unconfounded tests on their own during the joint posttest.

During the structured posttest with the experimenter directing the activity, parents never fully executed a single trial completely on their own. As shown in Table 5, all experiments were executed by children alone or by parents and children jointly. Unlike in the self-directed exploration during which, on occasion, parents executed experiments solely, during the joint posttest (while the experimenter was present) parents never executed an experiment completely on their own. Parents may have viewed this as a testing situation for their children in which their role was to assist; it was unlikely that the parents would dominate the materials and completely execute the experiments while the child watched.

A 2 (phase) x 2 (age group) repeated-measures ANOVA on the number of experiments executed by children alone revealed a significant phase-age interaction, indicating that younger children executed more trials individually in the Ramps domain, while older children executed more tests on their own in the Spring domain, $F(1, 28) = 5.09$, $p < .05$. This result suggests that as children needed more help in executing the trials parents provide more assistance; this was most likely to occur for younger children in the Springs domain, as the materials (springs and weights) in Task 2 were more difficult to manipulate than Ramp components. Previous research (e.g., Gleason & Schauble, 2000) demonstrated when parents and children engage in designing tests together, often parents dominate the conceptual aspects of the task, leaving the manual aspects to children. Because of the nature of the ramp task design (lifting two gates to run each trial), the overall percentage of joint executions in this study was generally higher as parents and children often took control of one Ramp each (to race).

Furthermore, parents and children were asked to explain the design of their experiments. As presented in the first section on children's CVS and Robust CVS use, the level of Ramp Robust CVS use was approximately 30% and 40% for parent-child dyads with younger and older children, respectively. In the Spring Joint Posttest, the levels rose to 42% and 48% for younger and older children. But, who actually provided these CVS explanations; did parents primarily construct them alone, did children, or did they construct them together? As shown in Table 6, parents and children shared responsibility for providing reasoning. Of the Robust CVS reasons provided in dyads with older children, older children on their own provided approximately 41% of the reasons. In dyads with younger children, about 22% of the Robust CVS reasons were provided by children alone. These results indicate that although parents sometimes modeled

Robust CVS use and collaborated with children to construct the strategy rationale, children alone provided approximately one-third of Joint Robust CVS responses.

Table 6: Percentage of Robust CVS explanations given by parents, children, or jointly for dyads with older and younger children

	Ramps			Springs		
	Parent	Child	Joint	Parent	Child	Joint
Younger	22.1	22.1	55.8	29.6	22.5	47.9
Older	22.9	40.8	36.6	33.2	41.6	22.3

Parent-child Conversation

Parents and children engaged in conversations while exploring the materials and designing experiments. There were four activities in which parent-child talk will be described to explore patterns relating to age group: self-directed exploration of Ramps and Springs and the Joint Ramp and Spring Posttests.

Parent-child Conversation during Self-directed Explorations

Description of Parent and Child Talk. In exploring parent talk during the self-directed exploration, we see that parent talk generally did not differ for parents of older and younger children. As seen in Table 7, parents talked similar amounts to older and younger children in each the of the Ramp and Spring activities. Parents were most likely to ask their children questions while exploring in both domains. After asking questions, the three most common types of parent talk were describing evidence, establishing specific goals for experimentation, and setting general goals. As the exploration of the Springs was significantly longer than Ramps, there were additional frequent categories of talk in Springs Common talk during exploration of Springs in addition to the above was talking about predictions, talk about replicating tests of variables, labeling, referencing the strategy, and talking about the causal status of the variables.

Additionally, the amount of child talk also did not differ significantly between older and younger children. Although parents were taking more often and engaging a larger variety of talk than were children, these findings illustrate that 5- to 8-year-old children were not only physically engaging in the activity of experimentation, but that were also active in conversing with parents about the activity in a variety of ways. The most common category of talk for children was describing evidence; only 4 children during the brief Ramp exploration and 2 children during the Spring exploration did not describe evidence at least once. The other categories were evenly distributed and equally infrequent during the brief Ramp exploration. During the Spring exploration, following describing evidence as the most frequent category, children often engaged in establishing specific goals, making predictions, discussing the causal status of variables, and labeling.

Table 7: Means (and Standard Deviations) for total talk of parents and children during Self-directed Explorations and Joint Posttests

	Self-directed Exploration				Joint Posttest			
	Ramps		Springs		Ramps		Springs	
	Younger	Older	Younger	Older	Younger	Older	Younger	Older
Parent	10.9 (5.3)	11.3 (7.0)	36.1 (8.4)	31.6 (8.9)	21.7 (9.7)	16.3 (8.2)	19.4 (8.6)	13.0 (10.6)
Child	4.3 (2.8)	3.9 (2.3)	10.9 (8.2)	15.9 (9.7)	9.8 (5.3)	9.7 (4.6)	7.5 (2.3)	8.9 (4.2)

For further analysis, parent and child talk was grouped into Planning and Evaluating categories. The Planning category consists of the following categories of talk related to the design of experiments: reminding of the strategy, labeling variables, setting general goals, setting specific goals, establishing roles, and checking levels of variables. The Evaluating category consists of the following categories of talk typically occurring following the execution of experiments while evidence is available: describing evidence, interpreting evidence, isolating effects of variables, talking about hypotheses, discussing the causal status of a variable, discussing replication of a specific trial or of a variable's effect. These two categories of talk were developed as an additional way to explore how parents and children negotiated collaborative experimentation, and together the categories accounted for 71% and 82% of parent and child total talk, respectively. Both parent and child talk consisted of primarily categories that were classified as Planning and Evaluating, however the remaining talk not in these categories focused on asking questions and making predictions.

As seen in Table 8, parents of older and younger children engaged in Planning and Evaluating talk similarly with both age groups. Although parents of younger children engaged in slightly more Planning and Evaluating talk with their children, these differences were not significant. Overall, parents engaged in more Planning talk than Evaluating talk, however they did engage in a fair amount of Evaluating talk, especially during the Spring activity. In exploring children's talk, the amount of older and younger children's talk did not differ significantly in either Planning or Evaluating talk during either the Ramp or Spring activities. Children engaged in two- to three-times more Evaluating talk than Planning talk. This may be due in part to the prevalence of describing evidence, which accounted for about half of children's evaluating talk.

Table 8: Means (and Standard Deviations) for parent and child Planning and Evaluating talk during self-directed exploration

		Ramps		Springs	
		Younger	Older	Younger	Older
Parent	Planning	5.2 (3.5)	4.2 (2.5)	14.7 (4.8)	12.6 (6.0)
	Evaluating	2.8 (2.4)	2.7 (2.2)	11.25 (3.2)	10.1 (3.6)
Child	Planning	.75 (1.3)	.93 (.9)	2.9 (3.2)	3.8 (1.0)
	Evaluating	3.1 (2.0)	2.6 (1.6)	6.0 (5.4)	8.6 (5.6)

Relationships between Parent and Child Talk. In this section, I will present findings that indicate a relationship between parent and child talk. To explore these relationships, we computed bivariate correlations between parent and child Planning and Evaluating talk to determine which of these categories of talk were related during self-directed activity. As seen in Table 9, much of children's own Planning and Evaluating talk was correlated. For example within each Ramp and Spring Session, correlations indicate that children's levels of Planning and Evaluating talk are related. Additionally, two significant correlations across Sessions (between children's level of Planning and Evaluating in Ramps with their level of Planning in Springs) indicate that children's patterns of talk or levels of engagement may be relatively consistent over time.

One particularly interesting finding relates parent and child talk in separate phases. The amount of child Evaluating talk while exploring Ramps is significantly correlated with the amount, during exploration of Springs one month later, of parent Evaluating talk and parent Planning talk. Furthermore, the amount of child Planning talk during Ramps is also correlated with the amount of parent Evaluating talk. These findings may point towards ways that parents and children build on joint experiences over time. If parents and children engage in an activity together while children engage in particular behaviors, exhibit certain interests, or demonstrate competency in particular areas, perhaps parents attend to this abilities and interests. In later related experiences, parents may recall children's type or level of engagement and this may influence how parents build on shared experiences with children over time.

Table 9: Correlation matrix for parent and child Planning and Evaluating talk during self-directed explorations

			Parent				Child			
			Ramp		Spring		Ramp		Spring	
			Plan	Eval	Plan	Eval	Plan	Eval	Plan	Eval
Parent	Ramp	Plan	--							
		Eval	0.30	--						
	Spring	Plan	0.14	0.24	--					
		Eval	0.09	0.10	0.28	--				
Child	Ramp	Plan	-0.09	-0.10	0.04	0.40 *	--			
		Eval	0.04	0.05	0.44 *	0.64 **	0.44 *	--		
	Spring	Plan	0.04	0.28	0.09	0.34	0.41 *	0.37 *	--	
		Eval	-0.12	-0.13	0.14	0.16	0.28	0.30	0.57 **	--

p < .05 : *
.01 : **

Parent-child Conversation during Joint Posttests

Description of Parent and Child Talk. Parent talk during posttests differed more between older and younger children than did talk during the self-directed explorations. As seen in above in Table 7, parents talked more to younger children during both Ramps and Springs posttests. These differences in amount of talk did not reach significance for the Ramps posttest; however, the differences were marginally significant for the total talk during the Springs posttest ($p = .078$). Perhaps the Springs activity was more difficult, especially for younger children and therefore parents increased their support during the testing phase for these children. In exploring children's talk, older and younger children talked very similar amounts during the Ramp and the Spring posttests.

Parent and child Planning and Evaluating talk during the joint posttests was also explored for differences in how parents and children negotiate joint experimentation during testing. There were no significant age-related differences for either parent or child talk during the joint posttest. In the posttests, these two categories accounted for 50% and 86% of parent and child talk, respectively. Parents engaged more in categories of talk that were not included in Planning and Evaluating categories, such as praise, questions, and predictions. Children's talk, however, continued to consist of primarily Planning and Evaluating talk. As can be seen in Table 10, parents in general talked much more about Planning than Evaluating, and they talked slightly more about this to younger children. Their levels of Planning and Evaluating talk were very similar in the Ramp and Spring posttests. Children, during the Ramp posttest, talked similar amounts about Planning and Evaluating. During the Spring posttest, younger children engaged in less Planning talk, but maintained their level of Evaluating talk. Overall, children engaged in more Evaluating talk than did parents likely because children were more likely to provide answers to the question regarding the dyads' findings of experiments. Children often answered this question by describing evidence or by stating a variable's effect, two frequent components of Evaluating talk.

Table 10: Means (and Standard Deviations) for Planning and Evaluating Talk during Joint Posttest

		Ramps		Springs	
		Younger	Older	Younger	Older
Parent	Planning	8.5 (5.4)	5.9 (2.9)	8.8 (5.2)	5.7 (5.0)
	Evaluating	1.3 (1.3)	1.1 (1.2)	1.6 (1.5)	1.0 (1.2)
Child	Planning	5.8 (4.2)	5.7 (3.6)	1.9 (1.5)	2.8 (2.1)
	Evaluating	5.6 (2.5)	4.5 (2.9)	4.7 (1.4)	4.6 (2.1)

Relationships between Parent and Child Planning and Evaluating talk during Joint Posttest. In this section, I will present findings that indicate a relationship between parent and child talk. To explore these relationships, we again computed bivariate correlations between parent and child Planning and Evaluating talk to determine which categories of talk were related during joint posttests. As can be seen in Table 11, this analysis again revealed that levels of child Planning and Evaluating talk within each Session are correlated. The analyses also revealed a negative correlation between child Planning talk in Springs and parent Planning talk in Springs. This finding suggests that if children were able to answer the experimenter's question related to planning talk (why did you design the test that way?), parents did not need to answer this question. Additionally, Planning talk occurred after parents and children were asked to design a test of a particular variable; if kids were doing well on their own during the design, then parents did not need to step in with as much Planning talk, such as reminding about the strategy and setting goals,

Table 11: Correlation Matrix for parent and child Planning and Evaluating talk during Joint Posttests

			Parent				Child			
			Ramp		Spring		Ramp		Spring	
			Plan	Eval	Plan	Eval	Plan	Eval	Plan	Eval
Parent	Ramp	Plan	--							
		Eval	0.07	--						
	Spring	Plan	0.35	0.16	--					
		Eval	0.10	0.19	0.19	--				
Child	Ramp	Plan	-0.05	0.23	0.01	0.08	--			
		Eval	0.09	0.23	0.21	0.10	0.61 **	--		
	Spring	Plan	-0.31	0.12	-0.43 *	-0.02	0.28	0.05	--	
		Eval	0.07	0.16	-0.14	-0.09	0.30	0.16	0.41 *	--

p < .05 : *
.01 : **

Relationships between Child Learning and Parent-child Activity

This section will explore relationships between child learning and other aspects of talk and activity during the study. To make these comparisons, relationships between Good and Poor Experimenter classification and various measures parent-child activity will be explored. First an analysis of parent-child experimentation will be presented, followed by an analysis of parent-child talk.

Relationships between Good/Poor Experimenter Classification and Parent-child Experimentation

To explore the relationship of learning and activity, the design and execution activities of the Good and Poor Experimenters are compared. As can be seen in Table 12, during the brief Ramp interaction, there were no significant differences found in how parents and children of the Good and Poor Experimenter groups shared responsibilities in the design or execution of experiments. However, during the Ramp posttest, while the two groups executed experiments similarly, there were significant differences in who designed the experiments. While the two groups had similar amounts of jointly designed experiments, children in the Good Experimenter group designed more experiments on their own (61%) than did children in the Poor Experimenter group (25%), $p < .05$. There was a marginally significant difference in the percentage of experiments designed by parents of Good Experimenters (2%) and Poor Experimenters (23%), $p = .06$, with parents of Poor Experimenters assuming sole responsibility for the design more often during posttest.

Table 12: Percentage of experiments designed and executed by parents, children, and jointly for Good and Poor Experimenters

			Ramps			Springs		
			Parent	Child	Joint	Parent	Child	Joint
Interaction	Execute	Good Exp.	16	26	57	9	40	51
		Poor Exp.	9	47	44	9	41	50
	Design	Good Exp.	18	28	26	20	33	27
		Poor Exp.	26	25	13	34	18	28
Posttest	Execute	Good Exp.	0	32	68	0	41	59
		Poor Exp.	0	55	45	0	55	45
	Design	Good Exp.	2	61	37	6	64	30
		Poor Exp.	23	25	48	13	10	65

During the Spring posttest, there were no significant differences during the self-directed interaction or joint posttest in how the parent-child dyads in the Good and Poor Experimenter groups shared responsibility for the execution of the experiments. However, in comparing who was responsible for the conceptual task of designing the experiments, there were significant differences in how families designed the tests in the Spring self-directed exploration and the joint posttest. During the self-directed interaction, children in the Good Experimenter group designed marginally more experiments on their own than did children in the Poor experimenters ($p = .053$), while the parents of Poor Experimenters designed more experiments solely and parents of Good Experimenters ($p < .05$). The distribution of design responsibility was slightly different than during the Spring posttest (but was similar to the distribution in the Session 1 Ramp posttest). There were generally fewer experiments designed solely by parents, and the difference between the two groups was not significant. Children in the Good Experimenter group again designed the majority of posttest experiments on their own (64%), whereas children in the Poor Experimenter group rarely did so (10%), $p < .01$. The majority of designs in the Poor experimenter group were collaborative (65%), while the Good experimenters collaborated with parents for 30% of designs, $p = .01$. Again, during Joint Posttests, parents likely viewed the activity as a testing situation for children in which they were there to help. Therefore in situations where children needed support to succeed (as was often the case for Poor Experimenters), the designs were likely to be collaborative, rather than solely completed by parents.

Relationships between Good/Poor Experimenter Classification and Parent-child Talk

Parent-child Talk during Self-directed Exploration

In comparing Good and Poor Experimenters, comparisons of parent-child talk in both the Ramp and Spring activities revealed interesting relationships to children's learning groups. During the Ramps exploration, children who eventually were classified as Poor Experimenters were more likely to have had parents who provided higher levels of specific guidance, $F(1, 20) = 6.87$, $p < .05$. Specific guidance was made up of two types of parent talk: setting specific goals and establishing roles. Parents of Poor Experimenters set specific goals more often during the ramps exploration (2.4) than did parents of Good Experimenters (1.1). Although establishing roles for experimentation was less frequent during the brief Ramp exploration, parents of Poor Experimenters were approximately four times as likely to establish specific roles for experimentation (Good = .18; Poor = .80). Although it may be possible that providing children with specific guidance would appear to encourage their physical engagement in the task, it may be that providing higher levels of structured guidance early in the activity may prevent children from engaging in higher level planning and preclude children taking an active role in understanding the experimentation process. It is also possible, however, that children who were eventually classified as Good Experimenters did not need parents to set in and set goals or be told who should complete which actions.

Another difference between parent conversation with Good and Poor Experimenters is that parents of Good Experimenters were, during the Spring exploration, more likely to reference the Session 1 activity, $F(1.20) = 4.40$, $p = .05$. Parents of Good Experimenters were more likely to explicitly mention the ramps or reference the previous time they were at the museum for Session 1 of the study. These parents also referenced the strategy twice as often with Good Experimenters (Good = 2.6, Poor = 1.3), but this difference was not significant.

There were also differences in how Good and Poor Experimenters talked to their parents. Table 13 presents the averages for child total talk and Planning and Evaluating talk during the Ramp and Spring self-directed activities for the Good and Poor Experimenters. Children who were eventually classified as Good Experimenters talked more, however this difference was more pronounced in the lengthier Session 2; Good Experimenters had twice as much experimental talk than did Poor Experimenters. Children who were Good Experimenters engaged in more Planning talk in both Ramp and Spring explorations and this was because these children were more likely engage in talk that set specific goals for the activity. Specific codes that Good Experimenters children engaged in during the Spring exploration more often that were components of the Evaluating category included describing evidence, talk about hypotheses, and talk about the causal status of variables.

Table 13: Mean child utterances during Ramp and Spring Self-directed Explorations

		Good Exp.	Poor Exp.	significance
Ramps	Total talk	5.1	3.8	
	Planning	1.5	0.4	*
	Evaluating	3.4	3.2	
Springs	Total talk	18.8	9.3	*
	Planning	5.6	2.2	*
	Evaluating	10.7	4.3	**

$p <= .05$: *
0.01 : **

Parent-child Talk during Joint Posttests

Parent-child talk during the joint posttests differed in many aspects for Good and Poor Experimenters. As can be seen in Table 14, in both the Ramp and Spring posttests, parents talked significantly more when talking with Poor Experimenters. Parents engaged in more Planning talk with Poor Experimenters through referencing the strategy more often and helping them remember the goals of the current test two- to three times more often. Additionally, during the Ramp posttest, parents guided Poor Experimenters through the activity by asking marginally more questions. These findings indicate that parents of Poor Experimenters probably knew that their children needed more support with the task and tried to support their performance by talking more, helping them to remember the strategy and goal of the current experiment.

Children's talk in the Good and Poor Experimenter groups also differed in several respects, but children's talk varied less in posttest than it did during the exploration. This could be partly due to the structured nature of children answering experimenter questions during the posttest. Although both groups of experimenters had similar amounts of total talk during the Ramp posttests, Good Experimenters talked a marginally significant amount more than Poor Experimenters during the Spring posttest and they were also more likely to talk about the goal of the test during the Spring posttest. Good Experimenters in the Spring Posttest engaged in more Planning talk; they demonstrated a trend towards more often fully stating the strategy and having more total strategy talk, and they were more likely to state the current goal of the test. These differences in talk between the Good and Poor Experimenters are additional indicators of Good Experimenters' knowledge of CVS and experimentation.

Table 14: Parent and child talk of Good and Poor Experimenters during Joint Posttests

			Good Exp.	Poor Exp.	significance
Parent	Ramps	Total talk	13.0	23.7	**
		Planning	5.0	10.2	**
		Evaluating	1.2	1.4	
	Springs	Total talk	10.0	20.8	**
		Planning	3.8	11.5	***
		Evaluating	1.3	1.2	
Child	Ramps	Total talk	9.9	10.2	
		Planning	6.1	5.6	
		Evaluating	4.9	5.5	
	Springs	Total talk	9.3	6.2	#
		Planning	3.9	1.1	***
		Evaluating	4.7	3.8	

p <= .10 : #

0.01 : **

0.001 : ***

CHAPTER 5

DISCUSSION

The two main sections of the discussion will address findings as they relate to Research Questions 1 and 2. In the first section, various aspects of children's CVS learning will be discussed, such as children's ability to transfer the strategy; differences in both learning and transfer will be discussed in relation to children's age. The second main section will address issues related to parent support of children's learning and transfer, and these will be discussed within the context of the four Synthesis Points.

Children's Learning and Transfer of CVS

Children aged 5- to 8-years-old engaged in experimental activity with parents in which they were provided training about a scientific reasoning strategy for designing unconfounded experiments: the Control of Variables Strategy (CVS). Families were provided opportunities to apply and transfer their learning of the strategy while exploring materials in two domains in two sessions spaced one month apart. In individual posttest measures, following training situated within the context of parent-child activity, 5- to 8-year-old children demonstrated an ability to use and transfer CVS.

Prior to the study, children's use of CVS was low, but a few children had a moderate level of knowledge about the strategy in the pretest phase. Two children correctly designed 3 of 4 correct experiments (1 older and 1 younger child), but neither child provided any evidence of Robust CVS understanding in pretest. Two additional children were able to provide the CVS rationale once in pretest, but these children had designed only two of four unconfounded tests of the target variable. Children's level of performance, an average of 23% correct, was higher than expected for children in these age groups. Previous studies using these tasks included four variables in each domain, significantly increasing the complexity of the task (Chen & Klahr, 1999, Triona & Klahr, 2003). Younger children's higher pretest performance could partly be a reflection of the decreased task difficulty.

Following training and self-directed exploration with parents, children increased their level of performance from 23% of the trials correct in the pretest phase to 64% of trials correct in Posttest 1. Both older and younger children demonstrated significant increases in the use of the strategy. One month later, following an exploration of a new domain with parents, children demonstrated that they were able to transfer the strategy by maintaining their use of CVS, averaging 60% unconfounded trials in Posttest 2. These results demonstrate that even young children can learn and transfer CVS when provided age-appropriate materials and support through learning in a context with parents. However, developmental differences in CVS learning were evident in Posttest 2 performance. Younger children, like older children, were able to learn CVS in a context with parents and transfer the strategy to be used on their own within the same domain as the initial learning. Whereas older children demonstrated a clear ability to transfer their learning to Session 2, increasing their Posttest 2 performance to 77% of trials using CVS, younger children failed to maintain or improve their performance. Younger children continued to use CVS in 45% of trials; this represents a significant decrease from Posttest 1 to 2. However, despite this decrease in CVS use, their performance remained significantly higher than in pretest.

Recall that Good Experimenters were defined as children who designed unconfounded experiments in 3 of 4 trials during *both* Ramp and Spring individual posttests. Because older and younger children exhibited these differences in Session 2 performance, another way to describe learning (rather than transfer) would be to explore how many children ever successfully used CVS in *either* Session 1 or 2 (designed unconfounded experiments in 3 of 4 trials). Looking back to Figure 4, we see that 10 of 14 older children had learned and used CVS in either Session 1 and/or 2. Of the 16 younger children, 10 of them also used CVS in either Sessions 1 and/or 2. Nine of these younger children learned CVS in Session 1, but only 3 maintained this level of performance to qualify as Good Experimenters, transferring their CVS learning to Session 2. In contrast, all 8 older children who learned CVS in Session 1 succeeded in transferring this learning to Session 2, and were categorized as Good Experimenters. Prior research has indicated that younger children's representations of problems are often tied to the specific, original learning context and this often results in difficulty perceiving the underlying similarity between analogous problems (e.g., Chen & Klahr, 1999; Flick, 1991; Gentner & Gentner, 1983). Although the Session 2 domain was a relatively near transfer (as will be discussed further in the next section), younger children appeared to have more difficulty making the transfer. Children's transfer abilities will be discussed in more detail, below, but perhaps, younger children's difficulties arose from two differences from the original learning context: the move from collaborative CVS use to independent CVS use, and the one-month time delay between Sessions 1 and 2.

In moving from a discussion of children's use of the strategy to their ability to also explain the strategy, we see that 5- to 8-year-old children demonstrated a more modest improvement in Robust CVS use. However, over the course of the study they increased their performance from 2% to 25% of experiments being unconfounded and accompanied by the CVS rationale. Children's ability to explain the strategy was another area in which age differences were observed. Only older children made a significant improvement in their ability to provide the rationale; younger children's performance only increased from 2% to 13% of trials providing the strategy. Older children, however, increased from 2% to 39%. Children in the study could simply be learning how to answer the experimenter's questions rather than developing and demonstrating a deeper understanding of the strategy. This fact however does not change the fact that some children were better able to provide the strategy rationale. However, these findings are consistent with prior research exploring changes in children's understanding and ability to explain their new understanding (Fender & Crowley, 2004, under review). While both older and younger children made significant shifts in understanding the intended function of an exhibit following an exploration accompanied by explanation, only older children made significant improvements in their ability to explain the change in their understanding. Although in this study parents clearly knew and could transfer the strategy, even they only averaged Robust CVS use for 75% of their individual trials. Additionally, during the joint posttests, although parents and children were nearly at ceiling in CVS use (around 95%), they only provided Robust CVS approximately 40% of trials. Children's individual CVS use was approximately 30% below their Joint CVS use with parents, and similarly, children's individual Robust CVS use was approximately 20% below their joint Robust CVS use with parents. Perhaps the overall exposure to joint CVS use and Robust CVS use influenced children's ability to provide similar answers on their own.

Near and Remote Transfer of CVS

How do individuals or groups generate ideas for solving problems in novel contexts? In exploring how scientists in world-class biology laboratories make discoveries, Dunbar (1997) described how scientists design new experiments, employing analogical reasoning as a main source of their new discoveries. Identifying analogical reasoning as a way "real scientists" engage in transferring knowledge, Dunbar's research demonstrated that analogical reasoning is often very useful in making discoveries, even when making close mappings of known strategies. The present study was designed in part to explore when and where children are able to transfer their learning of a scientific reasoning strategy by varying several dimensions of context. As described by Barnett and Ceci (2002), context can be broken down into (at least) six main dimensions: 1) knowledge domain (the knowledge base to which the skill is to be applied), 2) physical context (the location, room, experimenter), 3) temporal context (elapsed time between training and transfer), 4) functional context ("academic" task or "real world" tasks), 5) social context (task learned and performed alone or in collaboration with others), and 6) modality (hands on vs. linguistic, written vs. auditory). The distance of a transfer task can be determined then by the number of dimensions that differ between the training context and transfer context.

The design of the present study allowed for examination of children's performance at varying transfer distances. As can be seen in Figure 7, four contexts varied while two did not, as all tasks in the present study had similar physical and functional contexts. The physical context was the museum; although some families engaged in Sessions 1 and 2 in different rooms within the museum, the experimenter working with the child was always the same. The functional context was the same between training and the tasks, and overall the study activities could be viewed somewhere between an academic task and "real-world" activity. Many of the activities were "test-like" tasks structured by the experimenter, yet some families viewed this activity much like other activities or programming within the museum. Regardless of individual families' interpretations, they would likely view activities of Sessions 1 and 2 similarly.

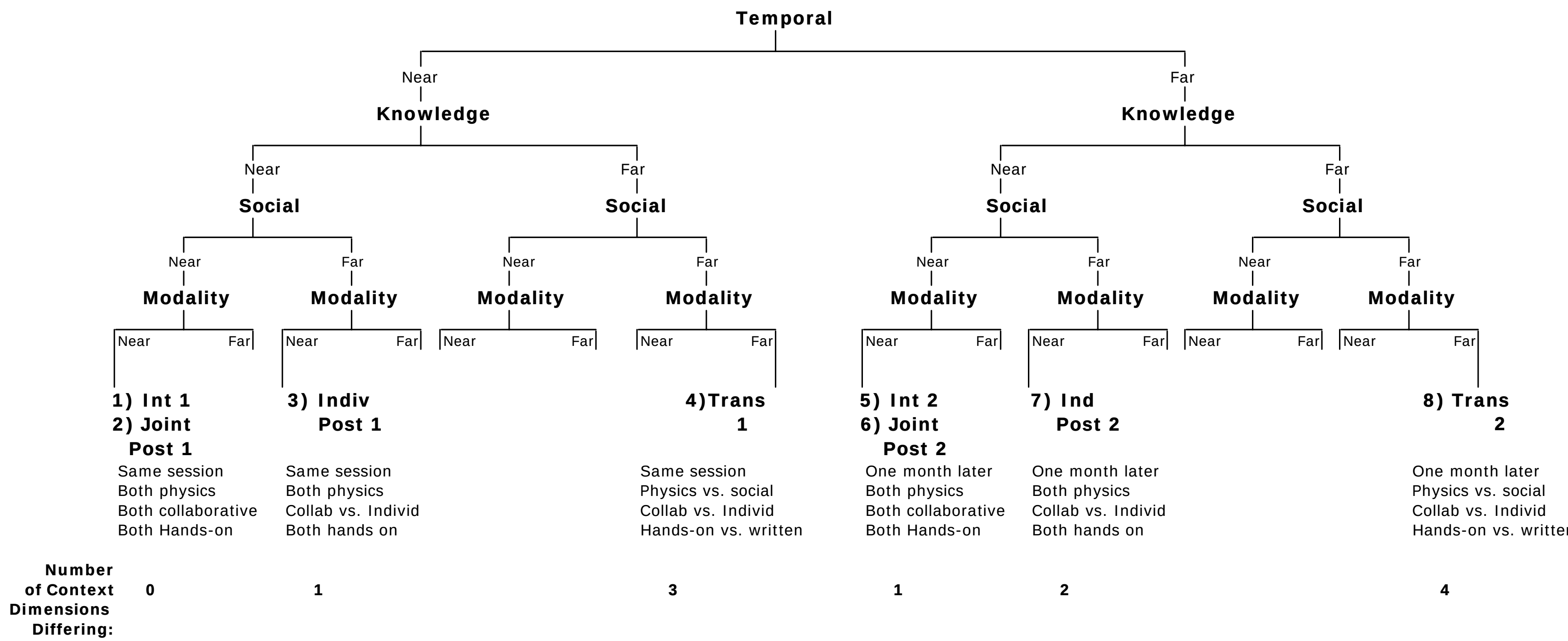


Figure 7: The Temporal, Knowledge, Social, and Modality dimensions of context for activities and measures in the present study involving transfer within near functional and physical contexts

As shown Figure 7, the four remaining dimensions of context – temporal, knowledge, social, and modality – varied across the activities and tasks. Each activity is compared to the original learning context, which occurred in a physical science domain at the start of the Session 1 with parents and children collaborating in a hands-on interview. Four types of tasks are discussed, with one of each occurring in each Session: the parent-child interaction (labeled Int 1& 2 in Figure 7), Joint posttest (Joint Post 1 & 2), Individual posttest (Ind Post 1 & 2), and Transfer task (Trans 1 & 2).

As described by Chen and Klahr (1999), transferring CVS requires children to first acquire the strategy in a specific domain and learning context and then access, map, and implement the strategy in a new context. The activities and measures in the present study differed from the training context on between zero and four context dimensions. Generally, children did well with very near transfer, engaging with parents in Interaction 1 and Joint Posttest 1, as these tasks did not differ on any dimensions from training. Additionally both older and younger children did well transferring their learning to the Individual Posttest 1, which differed from training only in the social context dimension. As transfer distance increased (three context dimensions of far transfer), both older and younger children exhibited equal difficulty on Transfer Task 1.

Returning for Session 2, families again did well transferring learning to Interaction 2 and Joint Posttest 2, even with the one-month delay and change in domain. This knowledge domain was still rated as a near transfer, as both tasks were in the physics domain. For the Individual Posttest 2, with two dimensions of far transfer – temporal and social – older children demonstrated they were able to transfer their learning, improving upon their previous performance. Younger children were less able to transfer their learning, demonstrating a decrease in performance from Session 1. However, their use of CVS remained significantly improved over pretest. Perhaps the switch to a new domain, although a relatively near transfer, was significantly more difficult for younger children, especially when the social context was changed. As previously mentioned, prior research has indicated younger children's learning is often tied to the specific, original learning context; this often results in difficulty in perceiving the underlying similarity between analogous problems (Chen & Klahr, 1999; Flick, 1991; Gentner & Gentner, 1983). Furthermore, in prior related research, 8-year-old children were shown to only be able to use their learning within the original problem context (Chen & Klahr, 1999). It should not be surprising then, that 5- to 6-year-old children demonstrated more difficulty than older children in making this level of transfer.

In the final Transfer task (with 4 context dimensions differing from pretest), again older and younger children exhibited equal difficulty in accessing and implementing the strategy. Prior research demonstrated that only fourth-grade children (10-years-old) were successful in transferring their learning when there were three different context dimensions between training and transfer, through this transfer was made at an extended, 7-month time delay (Chen & Klahr, 1999). However, despite children's generally low performance, children demonstrated an increased ability to apply CVS to the transfer task between Session 1 and 2. Although Transfer 2 had a fourth dimension – temporal – different from Transfer 1, children's knowledge and use of CVS had been refreshed during the parent-child self-directed exploration and perhaps many children's understanding was strengthened with use the application of the strategy to a new domain in Session 2. Additionally, children were familiarized in Session 1 with type of task and this may have made Transfer 2 easier for them.

This analysis of near and far transfer tasks further illuminates similarities and differences in abilities of older and younger children. Older and younger children performed similarly on many of the transfer tasks, with the primary age-related difference in transfer occurring in Session 2. In the Individual Posttest 2, younger children demonstrated particular difficulty in making this transfer, possibly indicating that increasing the number of context dimensions differing between the learning and transfer context increases difficulty, especially for younger children. However, this could also indicate that it is possible that differing particular context dimensions may impact older and younger children differently. Younger children were able to transfer their learning in Session 1 from the joint to individual posttests, however they were not able to maintain their level of performance in Session 2. It is possible that the temporal context made this transfer particularly difficult, but younger children's difficulty might be attributed to the knowledge context change, even though this dimension was labeled "near" transfer. Further research could examine whether it is generally the number of context dimensions differing that makes far transfer difficult or rather that particular context dimension changes result in increased transfer difficulty for various age groups.

Effects of CVS Knowledge on Children's Understanding of the Effects of the Variables

As discussed by Chen and Klahr (1999), little prior work has made explicit connections between the acquisition of domain-general process skills and domain-specific understanding. It would generally be expected that if children design confounded experiments, it would be more difficult to make inferences about a particular variable based on experimental outcomes. However, if children repeatedly design unconfounded experiments that provide clear evidence for valid inferences, they would presumably be able to revise misconceptions about variables' effects. Chen and Klahr (1999) demonstrated that children who were provided training and prompting questions (i.e., those who has significantly higher CVS scores) improved their domain knowledge. In the present study, when Good and Poor Experimenters were compared, there was no interaction found between Good/Poor Experimenter classification and content learning across phase. There was a ceiling effect contributing to this lack of differences, as both Good and Poor Experimenters made improvement in their understanding of the variables and were likely to now the effects of the three variables in each domain.

Additionally, increased CVS strategy knowledge may not have had as strong of an effect as in previous work due to a number of differences in the current procedure. First, children were exposed to more experiments than those they designed on their own during individual posttests because children designed experiments with parents during self-directed exploration and joint posttests. Often, especially in during joint posttests, experiments designed with parents were unconfounded. Second, besides observing these outcomes, parents sometimes discussed with children what they had each predicted in their individual content pretest and expressed surprise when their own (parents') misconceptions were revealed. The process of revising incorrect theories was made more explicit through discussion with parents – both for Good and Poor Experimenters. Again, this may have helped all children learn about the causal status of the three variables, even if they eventually were unable to design unconfounded tests on their own. Third, the fewer number of total variables in both domains in this study (three variables instead of four) ultimately made the effect of one variable more obvious, especially in comparing repeated outcome from several experiments. For instance, even if weight is the final variable tested (i.e., parents and children design tests for length and width of spring first), over the course of several experiments in replicating the effect of length, for example, parents and children may have used pairs of heavier weights in one test and pairs of lighter weights in other tests. From these crossexperiment comparisons, it is possible to observe how heavier weights make both the longer and shorter springs stretch farther down, and parents and children would often comment about this prior to the design of tests specifically for weight. Because of the multiple opportunities that both Good and Poor Experimenters had to learn about the causal status of the variables, this may have masked possible effects of increases in children's strategy knowledge improving their ability to make valid inferences.

Parent Support of Children's CVS Learning and Transfer

Parent's understanding of their children's abilities may impact the ways parents engage in shared activity. Parents had opportunities during the self-directed exploration activity and joint posttests to support children's engagement in scientific reasoning activity, and throughout this section of the Discussion, we will discuss differences in parent support that related to child age or ability. The discussion of parent support of children's learning and transfer will be organized around the four Synthesis Points in order to make further connections between these four issues and the parent-child activity and learning that took place in the present study.

Synthesis Point 1: Goal Negotiation

During shared scientific reasoning, parents and children work together to negotiate the goals of the activity. As demonstrated in this study, parents and children each engaged in establishing specific and general goals and sometimes they established roles for each other in the joint experimentation. As defined by Saxe (1992), goals that emerge in shared activity are a blend of sociocultural processes and the cognizing activities of the individuals involved, and these goals often shift as individuals participate in social interactions. The codes for general and specific goals in this study were developed to characterize common forms of parents and child talk that often referred to or proposed experimental actions to guide future activity. This type of talk seemed to implicitly state that planning was necessary and that there was a structure to the on-going experimental activity. Because of this, we hypothesized that parent-child talk that emphasized the on-going structure of experimentation might support CVS learning. However, a relationship was observed between increased parent levels of specific goal-setting and lower experimental abilities of children. That is, children whose parents provided more specific goals during Session 1 exploration were more likely to eventually be classified as Poor Experimenters. If parent goal-setting leads to decreased abilities of children to learn and use the strategy on their own, perhaps making general goals that maintain references to planning of experimentation without actually giving the "answers" to the next step in the activity (as setting specific goals often did) would better support children's understanding of the experimentation process. This is an issue for future research. However, it is possible the relationship could move in the opposite direction, in that lower child ability leads to increased parent goal-setting. Some parents may have perceived children's early difficulties and tried to compensate for this by supporting their activity by providing increased structure and guidance for experimental activity.

Related to the issue of setting goals for or with children is the idea of scaffolding and concept of the Zone of Proximal Development (ZPD) discussed previously. Again, the ZPD suggests that much of cognitive development occurs in social situations in which children's problem-solving activity is guided by adults or more experienced partners who structure activities and model problem-solving strategies. If a problem is too difficult for a particular child, no amount of support will result in learning, and conversely if a problem is too easy, support is not needed for a child to succeed. Additionally, an important component of this concept is that over time, as children become more competent participants in the activity, they begin to take on more and more responsibility, such as structuring the activity by, for example, setting goals (Litowitz, 1993). As Litowitz states, however, adult-child activity that considers the ZPD is often too “adultocentric”, and perhaps it is important to focus more of children’s behaviors, goals, and motives, as well as how the dyad works together to internalize roles and knowledge.

Would children aged 5- to 8-years-old who received CVS training have learned CVS using these simplified materials without parent support? Indeed, a few children in these age groups likely would have. Some children did not have difficulty understanding the strategy and easily answered the experimenter’s questions during training. They were interested and highly motivated to engage in the activity. On the other end of the spectrum, though, were children who, even with training and parent support, did not become good CVS users in either Sessions 1 or 2. Of the 10 children classified as Poor Experimenters, some did make improvements and were designing 50% unfounded experiments. Others, though, did not demonstrate that they understood the strategy or structure of the activity either while engaged in the self-directed exploration with parents or during the individual posttest. While it was informative for the purpose of this study to observe how parents guided Poor Experimenters through the activity and supported their performance, these particular children were currently unable to learn and use CVS.

It seems that for a small group of high and low performing children, respectively, that parent support, was either not necessary or was not sufficient for children to learn; the present task was outside of the ZPD of these children. However, some of the 11 children who became Good Experimenters clearly would not have learned the strategy without parent support. Parents worked hard to focus children’s attention and structured the exploration of the materials across experiments so that children gradually demonstrated to parents they could design an unconfounded test for the target variable. Overall though, parents supported children’s engagement with the task by reminding them of the strategy and helping them to focus on the current goal of their test (e.g., to design a test that would tell them for sure whether Ramp surface, for instance, makes a difference in how far the ball rolls). For the majority of children in the middle range, training and parent support was helpful to varying extents. With training and parent support, some children became Good Experimenters, some were good experimenters in either Session 1 or 2, but not both, and some made improvements in CVS use, but did not meet the Good Experimenter criteria.

Through this particular study, we are able to see how parent help engaged children in shared activity and to varying degrees, supported sufficient learning for children to be able to perform on their own. This study revealed that both older and younger children engaged in the task remarkably well. Most children demonstrated through their activity and conversation with parents that they were able to engage in scientific reasoning activity and contribute to the design of unconfounded experiments. During the self-directed explorations for example, between 20% and 38% of experiments designed were unconfounded experiments designed children alone. During the joint posttests, these numbers increased to between 36% and 49%.

Children were not only able to physically engage in the task, but they were also able to engage in extensive conversations with parents. There were not many differences in the overall amount of talk that older and younger children engaged in, especially during the self-directed explorations with parents. A few differences were observed during the joint posttests; older children were slightly more likely to state specific goals during experimentation in the Ramp posttest, while during the Spring posttest, older children were more likely to fully state the strategy (provide evidence of Robust CVS understanding).

Over time, parents and children encounter a variety of related experiences as children move through stages of readiness to engage deeply with various activities. If children first encounter activities that are outside their ZPD, parents may still learn about how to support children's present or future engagement in the activity, and then later build on these prior shared experiences as children's abilities change. As children's engagement and success with the task improves, parents can gradually cede more task responsibility to children. Additionally, parents can continue to connect current activities with prior ones, building on shared experiences over time. This idea will be elaborated upon in the section discussing Synthesis Point 3, Systems of Shared Knowledge.

Synthesis Point 2: Distributed Cognition

Parents and children engaged in joint scientific thinking is an example of distributed cognition, with each member playing a unique role. As parents and children designed experiments together, parent talk often served to focus children on the current purpose of the test, encouraging the generation of useful evidence. As children focused on the specifics of choosing materials for their tests, not only did parents help remind them of the current goal or focus of their test, but they also helped them to design unconfounded tests by reminding them of the strategy. They discouraged generation of uninformative evidence and modeled good testing strategies. Besides exposing children to more unconfounded experimental designs generally, engaging in shared scientific thinking and CVS learning with a more experienced partner distributed the cognitive load of designing and executing the tests between parents and children. This type of activity allowed children to engage in experimentation at their level, while parents were there to shape and redirect the activity when necessary.

In exploring how families executed experiments, slight age differences appeared. As discussed by Gleason and Schauble (2000), during joint scientific reasoning, parents often assume more difficult conceptual aspects of the tasks and delegate the execution of experiments to children. As children in the present study were significantly younger than the children in the Gleason and Schauble study (who were 9- to 12-years-old), the execution of experiments observed here were more collaborative. Perhaps because the materials in the present study were sometimes difficult for children these ages to manipulate (some Ramp pieces were large, some Spring pieces were very small or heavy), parents often collaborated with children in the execution of experiments.

During the self-directed exploration activities, overall there were not large differences in how parents distributed responsibilities for older and younger children. The talk between parents of older and younger children was very similar in terms of the total amount of talk and amounts of Planning and Evaluating talk. Although parents shared with older and younger children the execution of experiments in similar proportions, there were differences in how parents took responsibility for the design of experiments with older and younger children. Younger children designed significantly more experiments during the Ramp activity than older children, but during the more difficult Spring activity, older children designed more tests. Parents took sole responsibility for more test design in the Spring activity with younger children; as this task became more difficult, parents assumed greater responsibility for the more difficult conceptual aspects of the task.

The joint posttests also revealed differences in how parents engaged in activity with older and younger children. Parents generally talked more with younger children during both Ramp and Spring joint posttests. In the distribution of activity, the design of tests was more collaborative with older children, while parents assumed control for the design of tests more often on their own when with younger children. During the Spring posttest, overall there were fewer parent solo-designs. Collaborations were higher for younger children, while for older children, responsibility between designing on their own and designing in collaboration with parents was divided more evenly. Again, parents increased support for younger children during the joint posttest to help ensure their success. Perhaps parents, when taking more responsibility for the designing of experiments with younger children, whether solo or collaborative designs, engaged in additional talk as a way involve younger children in the activity and to hopefully help them better understand what parents were doing while designing experiments.

The concept of Distributed Cognition relates also to Research Question 1 and children's strategy learning. Although the impact of distributed cognition on children's learning cannot be directly established from the findings of this study, it is likely the case for many children that engaging with parents in experimental activity improved their ability to later design experiments on their own. Children appeared to have variable understanding of CVS following training and often parents structured the self-directed exploration and joint posttest activity in ways that appeared to further children's CVS knowledge.

Synthesis Point 3: Systems of Shared Knowledge

Through everyday and informal learning activities, children and parents develop systems of shared knowledge about science content and about processes of scientific reasoning together. Parents knew the strategy at the start of the study, but by experiencing the training session with children, parents may have learned more about how to talk to children about experimenting and about CVS, specifically. During the activity, parents could then refer to the shared training experience, and were often observed asking children if they remembered the “rule” or what they just learned together. Parents could then refer to or specifically restate the strategy concepts.

In exploring connections between children’s experimental abilities and parent support, several differences were found. During the joint posttests, parents of children in the Poor Experimenter group talked more. Although parents were not aware of how children had performed on individual posttests, through the repeated shared activities of training, exploration of Ramps and Springs, and joint posttests, parents had many opportunities to observe how their children engaged in the tasks. However, parents did not talk differently with Good and Poor Experimenters during the self-directed exploration; their total talk, and planning/evaluating talk were very similar. The differences emerged in posttest when parents were likely trying to support Poor Experimenters’ performance so they would succeed in designing unconfounded experiments in the testing situations.

By the time families returned to the museum for Session 2, they had many aspects of Session 1 they could refer to. Parents who explicityly reminded children of their first visit to the museum for the study were more likely to have children that continued on to be independent Good Experimenters. They helped children to remember the Session 1 by referencing it generally (“remember what we learned the last time we were here”), referring to the specific activity (“you probably thought we’d be using those Ramps again”) and also reminding them of the strategy specifically (“we can only have one thing different”). As parents build knowledge of how they engaged in the activity with children, these memories may also begin to shape subsequent shared experiences. For example, children’s levels of Evaluating talk during the Session 1 activity was related to parents’ levels of both Planning and Evaluating talk in Session 2. In this way, parents may be sensitive to children’s particular interests or abilities and use this information to influence patterns of future shared experiences. Therefore, beyond building a catalog of facts and processes that families previously engaged in and can later reference, parents may use this information to shape the course of future related activity. The parent-child literature often focuses on the role of parents in helping children accomplish activity, solve problems, or use new strategies (e.g., Freund, 1990; Gauvain, de la Ossa, & Hurtado-Ortiz, 2001; Saxe et al., 1987). Beyond the issue of helping children be successful at an activity, some work has begun to focus on the role that parent talk might play in annotating children's observations and experiences to bring parent and child understanding into alignment (Rogoff et al., 2003) or to make the shared experience more easily remembered (Boland et al., 2003). Parent talk can function to mark experiences in ways that communicate interpretation and this may be a central mechanism of constructing shared understanding across many domains, including scientific thinking. By changing children's understandings, talk can both build shared knowledge and then later be used to extend future parent-child activity by referencing prior experience.

Synthesis Point 4: Problems of Communication

Joint scientific thinking can be hindered by problems of communication. First, parents are often unaware that aspects of scientific thinking that are self-evident for parents can be difficult for children. Second, young children often know more than they are able to explicitly talk about with their parents. In general, with older and younger children, parents talked in similar ways and amounts, and had similar engagements in the activity. Additionally, older and younger children generally talked and engaged in the activity in similar ways. Differences in parent-child talk and activity were found to be based more on children's abilities – for the groups of Good and Poor Experimenters. In these ways, parents and children were communicating well. Parents were sensitive to children's abilities, and during the joint posttests tried to support the poorer learners by providing more overall support; these parents referenced the strategy more often and reminded children of the goal of the current test. In exploring differences during the self-directed explorations, parents were observed giving more specific guidance to Poor Experimenters in the form of setting specific goals and establishing roles. From these findings we do not know if these types of parent guidance led to decreased learning or if these parents determined very early on in the brief Ramp exploration that their children were having difficulties in understanding the strategy. However, parents of Good Experimenters were more likely in Session 2 to explicitly reference Session 1. Perhaps if parents of Poor Experimenters had done this more often, they could have helped raise children's performance, at least in Session 2, which would have moved them to a "middle learning group": those who hadn't learned in Ramps, but continued on to learn in Springs. These issues may be less "problems of communication" and more of an issue of needing to help parents understand specific ways they can support children's learning and transfer.

Another measure of parents' understanding of children's knowledge was parents' answers about whether they believed children viewed the activities as similar or different. Eight of the 11 parents of Good Experimenters believed their children saw the similarity between the two activities. Only 3 of the 10 parents of Poor Experimenters reported they felt their children understood the similarity. This finding indicates that there were not problems of communication between parents and children about understanding the similarity of the two tasks, and that for at least the highest and lowest performers, parents were generally correct about children's perception of the task similarity.

In exploring age-related communication issues, parents were observed interacting with younger and older children in generally similar ways; there were not large age-related differences in parent-child experimental activity or in conversation. However, ultimately there were age-related differences in patterns of learning. This is one important area in which there may have been problems in communication. Perhaps parents could have supported younger children differently, if they knew younger children had more difficulty in transferring learning across domain and setting. In this respect, everyday and informal learning environments could be designed to support parents in helping younger children make connections across related activities and begin to build stronger connections. But, because older and younger children generally were engaging successfully in the task in similar ways with parents, perhaps parents could not observe or foresee this particular area of trouble children would have in engaging in the task independently. One observed difference in children's activity could have cued parents to younger children's difficulty in Springs CVS use; younger children had proportionally fewer independent unconfounded designs during the Springs self-directed activity. Although there were a fair number of collaborative designs, perhaps parents could have scaffolded the activity for children in a way that eventually required them to independently design more unconfounded experiments on their own. Although younger children had about 50% less independent designs in Springs than in Ramps, the low total number of experiments during the brief Ramp exploration makes this a difficult comparison. Parents may not have noticed this change in proportion of child designs and having children as young as 5- to 6-years old design 50% of unconfounded tests either on their own or in collaboration with parents could have been viewed by parents as rather successful engagement in the task.

Conclusions

As demonstrated in previous work, young children perform relatively poorly in scientific activities in which they design experiments to test the effects of variables when they are not provided training or support. However, this poor performance does not reflect an inability to understand the Control of Variables Strategy. In answer to Research Question 1, when children, even as young as 5- to 8-years old, are provided training in CVS in the context of an age-appropriate activity situated within parent-child activity, they are able to learn this strategy. Additionally, following a one-month delay, children are able to engage with parents in designing tests, successfully transferring the learned strategy to a new domain. They are then able to transfer their learning from a collaborative social context to use the strategy on their own in individual testing situations. Older children demonstrated that they are better able to transfer the strategy than are younger children. No older child who learned the strategy in Session 1 failed to transfer this learning to Session 2. Although they were able to make a moderately far transfer (to a new domain in a different social context at a one-month delay) they generally were not very good at making the furthest level of transfer.

Overall, younger children demonstrated that they were able to learn CVS as well as older children and transfer that learning across social settings, within the same domain. When younger children engaged in Session 2, following the one-month delay, they transferred their learning when using the strategy with parents. However, they demonstrated difficulties in making moderately far transfer to a new domain, in different social context following a lengthier delay. Noteworthy, however, was that younger children who did successfully learn the strategy and were able to transfer this learning were also very good at making the far transfer. This small group of children was the highest performing on the transfer task, averaging over 90% correct on the two Transfer tasks.

In exploring answers to Research Question 2, this study illuminated ways that parents and young children and engage in shared scientific activity and build on subsequent related activity. In particular, this study helps us understand ways in which parent support may be successful or unsuccessful in helping children to learn a scientific reasoning strategy and later, transfer this learning. To support children's engagement in scientific reasoning activity, parents vary their support in the design and execution of experiments; parents sometimes take sole control of these activities, sometimes collaborate with children, and sometimes allow children sole responsibility for design and execution. Furthermore, parents engaged in talk to support child engagement and learning. Parents reminded children of the strategy details they were trying to apply and redirected activity to support the generation and evaluation of useful and interpretable evidence. In looking specifically at how parents support transfer and to answer the second component to Research Question 2, we again saw how parents sometimes reminded children of prior shared activity; parents who did this were more likely to have children who later became Good Experimenters. As we learn more about the specific context dimensions that most strongly influence children's ability to transfer, parents and other educators of younger children can use this information to better align the learning and transfer situations. More research is needed to specifically address the question of how parents can successfully support transfer of varying distances. Additionally, further research is needed to make causal connections between particular types of parent support or patterns of engagement and children's resultant learning.

Limitations, Implications, and Future Directions

In this section, limitations of the findings of the current study will be discussed. Having acknowledged these limitations, I will then present implications of the findings of this study for early childhood education and museum learning. To conclude the discussion, directions for future research will be presented.

To begin the discussion of the limitations of this study, it is important to acknowledge particular characteristics of the study participants. They were families who were visitors of the Children's Museum of Pittsburgh and these visitors are typically middle- to upper-middle class. Additionally, 80% of the parents participating in the study had completed a bachelor's degree or graduate degree, and were thus highly educated, and not representative of a broader group of educational backgrounds. To recruit families for this study, parents and children were provided a brief description of the study that focused generally on the goals of the research, but also on the need for family participation in two lengthy sessions spaced one month apart. Because of the large time commitment and the need for families to return to the museum, these families were compensated with a choice of a family museum membership or a gift certificate to the museum gift shop. The families who decided to participate were typically frequent museum-goers, and were thus interested in obtaining a year-long family membership. Because the participants of the study were drawn from this specific group of parents who are interested in and motivated by maintaining continued museum activity, these findings may not generalize to the broader population. These characteristics of study participants limit the generalization of the study.

In addition to the issue of selection of participants, there may be questions related to how the lengthy, highly-structured setting of the study may generalize to everyday or brief, spontaneous parent-child reasoning activities. Although both sessions averaged 40 - 45 minutes each, the segments of the activity in which parents and children engaged in activity without the experimenter ranged from 2.5 to 12 minutes. Thus, these portions of self-directed activity are typical of the length of many parent-child everyday explorations of novel items with young children. Furthermore, in order to learn more about parent-child activity, it is important to move between studying spontaneous activity and controlled activity. This study was designed to fall on the more structured end of the continuum of parent-child learning activities in order to build directly on prior studies of individual child learning (Chen & Klahr, 1999) and to first determine if young children could in fact learn CVS. Now that we have observed that young children can learn this strategy, other less structured, more spontaneous methods could be employed to improve generalizability to natural parent-child activity that occurs outside the structured research setting.

Despite these limitations, the findings of this study have implications for early childhood education, for museum exhibit and programming design, and the design of other everyday settings. This study demonstrated that training in a scientific-reasoning strategy that was situated within parent-child activity could result in increases in young children's use of the strategy. Children therefore are able to learn useful science information at a young age through direct instruction. Although all instruction with children of these ages need not be so directive, this method of instruction was effective at conveying a strategy that children are unlikely to begin using on their own without training. Because this is a fundamental strategy in scientific reasoning, having young children exposed to the strategy at an early age may improve their later ability to learn this strategy even more deeply. Furthermore, increased competency in early scientific activity may also learn to increases in pursuing increased involvement in science activity and learning both in everyday and formal school settings.

Understanding more about the kinds and levels of support parents provide young children during shared scientific reasoning can inform designers of early learning activities, in museums or in schools, of the kinds of support that result in particular types of learning. In this study, a relationship was observed between higher levels of parent specific guidance (setting specific goals and establishing roles for the activity) and lower strategy use by children. Although we can not make causal statements based on the findings in this study, understanding relationships between conversation and learning can help museum exhibit designers to provide better support to parents within the museum setting. If future work provides a causal link between more open-ended goal-setting and children's increased understanding of scientific activity, then signage and other forms of activity support (e.g., floor staff, family guides) can communicate the types of parent support that is most beneficial for children's learning to parents during shared activity with their children. Knowing particular strategies that are effective for parents could help shape ways early childhood educators design activities and provide instruction for young learners.

The future directions presented here are based on the findings of the study, and the limitations and implications discussed above. First, to improve the generalizability of the findings, future work could recruit participants from various populations from outside of the museum context. Doing so would broaden our understanding of how a broader population of parents support children's activity in both unstructured self-directed activity as well as in directive activity with an experimenter in a testing situation. Furthermore, exploring parent-child scientific reasoning during less structured activity will help create a better understanding of everyday parent-child interactions. Future research should continue to balance more structured scientific activity and spontaneous activity to maximize control of the areas being studied while maintaining authenticity of activity and interaction patterns.

This study revealed specific age differences in children's ability to transfer their learning. In future studies, I plan to explore specific issues related to the conditions under which younger and older children are able to transfer their strategy learning. Exploring how changing particular context dimensions of far transfer impacts older and younger children's abilities to transfer learning may improve our understanding of how to best support children's learning and transfer. The knowledge of whether matching particular aspects of the learning and transfer contexts are necessary for successful transfer for children of various ages can improve the design of teaching materials and activities for use in schools and museums.

Lastly, in my future work I plan to future explore whether and how specific types of parent support are causally linked to various types of learning. In this study, a relationship was found between parents providing higher levels of specific guidance and lower child use of the strategy, for example. It could be the case that higher levels of structured parent guidance may facilitate children's physical engagement in the activity, but possibly preclude children from developing a deeper understanding of the strategy. However, it could be that parents were aware of children's lower understanding and ability to use the strategy and provided a high level of guidance from the very start of the activity. Future research could improve our understanding of this relationship and other patterns of parent-child activity and conversation observed in this study by investigating and establishing causal links between specific types of support and resultant learning. This study along with future research on parent-child shared scientific reasoning that builds on these methods and findings will further our understanding of the development of children's early scientific-reasoning abilities. Continued work in both laboratory and everyday settings is necessary to better understand how social interactions shape children's cognitive development.

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