CHILDREN AS EXPERIMENTERS:
ELEMENTARY STUDENTS' ACTIONS IN AN EXPERIMENTAL CONTEXT WITH MAGNETS

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Abstract

In science education the nature and value of science laboratory activities have become the subject of critical debate. Some science educators argue that a better understanding of what students do while purposefully engaged with materials would provide some answers. The intent of this study is to explore elementary students' actions and the knowledge they use while designing and conducting experiments.

Four dyads each from grades 4 and 7 participated in three events. First, each pair was presented with a question (Which magnet is strongest?), two sets of magnets (one set at a time) and materials. The researcher observed and videotaped dyads' actions with materials until they made a conclusion for both magnet sets. Second, the researcher presented dyads with a selective set of materials to further explore their conceptions of magnetism. Finally, the pairs of students were interviewed while they watched the video of themselves experimenting during the first two events. The data were analyzed using an action theory perspective which emphasizes the cognitive nature of action.

Students' models of magnetism were constructed from the data. Students used more than one model to explain different effects they observed. The designs of student experiments were grounded in their operational knowledge of the materials. Dyads generated data from a series of experiments whereby they manipulated different materials in a variety of ways. Dyads who obtained variable data did not repeat experiments to confirm or disconfirm results; rather they used specific strategies to make conclusions. The designs and procedures of experiments of students from both grades were similar, likely due to their common knowledge of the materials and their limited experience with open-ended tasks.

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"Grown-ups never understand anything by themselves, and it is tiresome for children to be always and forever explaining things to them."

The Little Prince by Antoine de Saint Exupéry

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CHAPTER 1

> Like my mom once said, in high school they gave you some chemicals to mix together and they told you what would happen. If they give you those chemicals to mix and didn't tell you what would happen, that would be an experiment.
>
> - Adam, grade 7

The Problem

The Role of Laboratory Work in Schools

In science teaching, the role of laboratory work remains loosely defined (Hegarty-Hazel 1990) and represents a diverse range of expectations aimed at science classrooms. While some science educators emphasize students' development of technical skills in laboratory activities, others envision the laboratory as an environment where students acquire scientific knowledge of certain phenomena (Woolnough & Allsop, 1985). Other roles attributed to the laboratory are students' development of processes of scientific enquiry (Millar, 1989), the enhancement of scientific attitudes and the enjoyment of science (Gardner & Gauld, 1990). For students, laboratory work presents a range of experiences involving structured activities, school science apparatus and science topics (Woolnough & Allsop, 1985).

Science education reforms of the early 1960's have influenced significantly current concepts of laboratory work (Layton, 1990). During that time, many science educators argued that the methods of scientific enquiry should be a primary goal of science teaching. Gagné (1963), an ardent supporter of a 'science process' approach for students, argued that traditional science courses emphasized facts and theories and did not encourage "the attitudes of enquiry,

the methods of enquiry, the understanding of enquiry" central to scientific investigation (p. 144). He advocated that "A student should be provided with opportunities to carry out inductive thinking; to make hypotheses and to test them, in a great variety of situations, in the laboratory, in the classroom, and by his own individual efforts" (p. 146).

Central to the intentions of a 'science process' approach was the laboratory. For students, laboratory experiences were to provide the means for learning the processes of science (Layton, 1990). This framework accounts for the emphasis on scientific processes in the science curricula over the last two decades (Roberts, 1982). Currently, processes are identified in most science curricula as a set of basic skills (e.g. observing, classifying) for primary students and integrated skills (e.g. controlling variables, experimenting) for intermediate students.

While a science process approach provided a new impetus for the use of laboratory activities, in recent years science educators have begun to examine critically the potential learning during such activities. According to Hegarty-Hazel (1990), there are "vehement critics who have claimed student laboratory work is simply an empty ritual, time wasting and expensive" (p. 3). Questions regarding what is achieved or what could be achieved during laboratory activities "have no adequate answers." She goes on to say, "What is needed is not just more and better laboratories but rather a much better understanding of the interactions between learning in the laboratory and elsewhere" (p. 27).

There are at least three general concerns expressed by science educators regarding the current practice of laboratory work. First is the apparent neglect of the personal knowledge that students bring to laboratory activities from their prior experience. Research shows that prior to formal lessons in science, students have beliefs about natural phenomena that are topics included in science curricula. Their beliefs often differ from what they typically encounter

during science lessons and in textbooks (Claxton, 1982; Driver & Oldham, 1986; Gilbert & Watts, 1983; Osborne & Bell, 1983; Osborne & Wittrock, 1983). These studies which have examined student prior knowledge about specific science topics include kinematics (Trowbridge & McDermott, 1981), temperature (Strauss, 1981), heat (Erickson, 1979), and light (Rice & Feher, 1987). Studies show that students are strongly committed to their beliefs (based upon their experience) and are unlikely to alter them for what is presented in the science lesson (Gunstone & Watts, 1985; Nussbaum, 1985; Tiberghien, 1984). Also, students bring their personal knowledge to experimental activities of the science classroom which affect their interpretation and observation of an experiment (Driver, 1983; Hodson, 1986; Cauzinille-Marmeche, Meheut, Seré & Weil-Barais, 1985). For example, Solomon (1988) conjectures that intuitive ideas "prestructure observation in line with the expected outcome. Thus an experiment is likely to confirm what we already think we know" (p. 105). Hence, the repertoire of student knowledge documented in science education research strongly suggests a re-appraisal of laboratory work in terms of eliciting and acknowledging the role of student beliefs.

Second, laboratory activities which propose to demonstrate scientific theories to students, often presuppose an inductive model of enquiry (Carey, Evans, Honda, Jay & Unger, 1989; Gott & Welford, 1987; Millar & Driver, 1987), whereby students are to observe and induce particular concepts. Many science educators now argue that an inductivist approach to school laboratory activities is beset with assumptions (Driver, 1983; Finley, 1983; Harris & Taylor, 1983; Hodson, 1985). To begin with, there is no step by step procedure which will ensure that students will make an inference from observations that will match a scientific concept. Harris and Taylor (1983) posit, there is no "watertight chain of inference from sensory input to universal proposition - from the rolling trolleys

on a bench to Newton's Second Law of Motion" (p. 279). These authors suggest that all observation is theory-laden and therefore open to multiple interpretations. Head (1985) questions the inductive model in science teaching, "...the survival of this belief, certainly in a simplistic form, is remarkable, for it has been challenged by scientists, it conflicts with evidence about the nature of perception and cognition, and it ignores the influence of the social organisation of science" (p. 3).

Also, an inductive approach to science activities implies to students that scientific theories are formalized generalizations or regularities in nature based solely on empirical observation (Hodson, 1988) and that such observation precedes theory (Millar, 1989). Absent from this view is the idea that scientific theories go beyond sensory experience. For instance, we may see iron filings in a specific pattern around a magnet, but we cannot see the magnetic field that magnetic theory suggests is causing the pattern (Harré, 1986). In a similar sense, we can see an object fall to the ground, but we do not see "gravity."

The current view from the philosophy of science is that observation is driven by theory, and it is through theory that observations become meaningful. For example, when a biologist looks through the microscope, she will have an expectation of what may be observed since she has an idea of what features are relevant. Harré (1986) argues that "without some prior idea of what to expect, the results of experimental science are usually opaque" (p. 2).

Finally, many science educators, including this researcher, are concerned about the utility of a "recipe approach" to teach the processes of science or to demonstrate theories. Tinnesand and Chan (1987) criticize this approach and state, "Labs consisting of detailed lists of materials and equipment needed, procedures to follow, data to collect, calculations to make and questions to answer don't train students to think. Only to follow directions and that's not

science" (p. 42). By applying a set of procedures to a given problem and materials, the students are meant to infer scientific principles embedded in the activity and arrive at a correct solution.

When recipe-type activities are implemented in the classroom, often a paradox arises. On one hand, students explore phenomena, collect data and make inferences about it; on the other hand, they ask, "Did I get it right?" since their outcome should match the expected outcome of the lesson (Driver, 1983). Hodson (1985) acknowledges the detrimental effects of this approach on children, "Children are frustrated because they frequently make observations and discoveries which the teacher, because of prior theoretical knowledge, dismisses as irrelevant or wrong" (p. 4). Claxton (1982) describes this problem eloquently in his critique of "school science",

> Here [in the laboratory] he will be given a small amount of magical experience and a large amount of talk, and he will be told that this fairyland of moles and pipettes, rheostats and ribosomes is somehow more 'real', more 'true' than the everyday world of custard and Granny and bath-times. He will learn that in this 'real' world his own experience is untrustworthy, and that there is a 'reasonable' distinction between what did happen and what should have happened. (p. 14)

Similarly, a grade 4 boy in the present study describes the paradox, "If it was an assignment and I had to get it exact, then I'd go for the book [textbook], otherwise I'd find it out myself."

Also, in activities which follow pre-designed procedures, different ways of experimenting are not considered, nor are the interpretations students make of those procedures. Hodson (1988) states,

> Science teachers should recognize that science has a range and variety of methods and the particular methods selected on any occasion depend on the particular circumstances. Scientific Method, like the knowledge it produces, changes and develops in response to the context of inquiry. (p. 60)

Millar and Driver (1987) also argue that the methods of science and science processes presented to students need more careful analysis, and that the current philosophy of science does not support the view that a "clearly describable method of science, consisting of a set of identifiable 'processes', exists" (p. 36). Barnes (1985), for example, views scientific enquiry as a craft where the scientist has tacit knowledge of apparatus, abstract objects (e.g. mathematical proofs) and scientific tools (e.g. statistics). In this view, the scientist's 'craft' comes from the practice of investigation.

Tinnesand and Chan (1987) suggest that students be given some opportunities to design their own labs and be given challenging puzzles to solve. The authors cite their own experiences, "We don't provide a list of procedures; our students must use their knowledge of concepts previously studied to develop their own. Abstract concepts become real. And the students start asking more intelligent questions - about concepts, about alternatives" (p. 44). The idea of students planning, designing and performing their own experiments has been promoted by several science educators. Woolnough and Allsop (1985) assert that in such activities students develop some practical skills and techniques (e.g. use equipment, make observations and take measurements), gain experience in problem solving, and "get a feel for phenomena." Gardner and Gauld (1990) are critical of the "tedious exercises leading to a 'right' answer" and argue that

students should be given some control over the procedures for arriving at a solution. In the latter case, the student as experimenter becomes a manipulator of materials rather than he or she being 'manipulated' by a set of procedures.

In short, science laboratory activities have become the subject of increasing critical analysis. Two clear directions for research and science teaching are apparent. One direction is to extend the existing qualitative research that examines what students at different grade levels can do in an experimental setting without a recipe to follow. The other asks research and teaching to consider the role of student knowledge in laboratory work. A "constructive epistemology" (Carey, et al., 1989) would provide a useful perspective for both teaching scientific process and investigating student knowledge in action. This study addresses the two directions by exploring, in depth, the action and knowledge elementary school students use as they design and implement experiments. The theoretical frame of the study is Action Science which is grounded in a constructivist world view.

The Child as Scientist

The metaphor, "child as scientist" is widely used. One interpretation suggests that children, like scientists, attempt to explain phenomena in order to make sense of their environment (Gauld, 1989; Kuhn, 1989). For example, Claxton (1982) writes that the child is like the scientist in the strict sense that "both are theorists and experimenters." He adds, "The sensory-motor child is a lively and intelligent scientist, albeit an intuitive one. He formulates hypotheses, emits behavioural experiments, notes the consequences and modifies the content, scope and theory accordingly" (p. 11). Woolnough and Allsop (1985) have a similar view, "We...see students as scientists in their natural way of working; each naturally motivated to explore their world and seek to

interpret it for themselves and then make sense of it" (p. 32). Carey (1986) conjectures that children, like the scientist, construct and revise conceptions as they interact and experience phenomena in the world about them.

Other researchers agree that knowledge is constructed by both student and scientist but argue that young students do not think "scientifically" (Kuhn, 1988; McClelland, 1984; Moshman, 1979). Osborne and Bell (1983) explain that "children's science" (children making sense of the world) differs from scientists' science in the following three ways. First, young children do not have the capability to use abstract reasoning to the degree that scientists do. They tend to view the world in a self-centered perspective and "consider only those entities and constructs that follow directly from everyday experience" (p. 2). Second, children are not concerned with coherent and non-contradictory explanations for a variety of phenomena. Driver, Guesne and Tiberghien (1985) have concluded from their studies that the child "does not possess any unique model unifying a range of phenomena that the scientist calls equivalent" (p. 3). For example, in work done on children's conceptions of light, the children used different models for the propagation of light to explain images and shadows (Feher & Rice, 1988; Rice & Feher, 1987). Third, Osborne and Bell argue, "everyday language leads children to have a view distinctly different to the scientists' view" (p. 2). Thus, everyday meaning of words tend to shape children's ideas or concepts. For example, for children friction and force have a different meaning than for scientists (Osborne & Wittrock, 1983).

Consequently, Kuhn (1989) argues that the metaphor, child as scientist, is misleading. She concludes the young students do not have the same competencies as the scientist, such as the ability to differentiate between theory and evidence. Scientists, she states, are able to reflect upon and articulate a theory and know what evidence would contradict that theory. Moshman (1979)

captures the essence of this argument by suggesting that children think through (with) theory and do not think about theory as the scientist would. This view infers that scientific thinking involves a conscious metacognitive level of reflecting about theory that children's thinking does not. Like Kuhn (1989), McClelland (1984) distinguishes between the scientist and the child.

> To suppose that children are scientists of a sort when they think about such phenomena seems to me to misconstrue totally the meaning and purpose of science. The distinction between such thinking and that of a scientist identified by Osborne et. al. is categoric, not one of degree. (p. 1)

He further argues that "interpretation of phenomena in terms of reproducible, explicable and causally related events are not automatic features of human thought" and are thus more the purview of the scientist than that of the child (p. 1).

Although different interpretations of 'the child as scientist' metaphor exist, the assessment of student experimental abilities most often relies on the comparison of novice student to expert scientist. This comparison is problematic for three reasons. First, is the lack of documentation of a clear and realistic definition of what entails expert 'scientific' thinking. There is little evidence to suggest that scientists thinking is different to that in which the artist or the mathematician engage. Kuhn (1989) herself admits that no strong claims can be made regarding "the range of thinking processes that professional scientists actually use as they think about scientific problems, on the bases of the limited evidence available on this subject" (p. 674). Second, are the differences in the knowledge between the student and expert scientist. The education, training and experience of the scientist is considerably greater than that of student. Hawkins

and Pea (1987) describe the differences between the students and the scientist in terms of two distinct cultures. The culture of the student represents a pragmatic point of view while the culture of the scientist represents the canonical standards of science. Third is the importance of a community of scientists. In a scientific community procedures, conventions and standards are set by the consensus. Barnes (1985) proposes that we think about scientists in terms of a community where "individual scientists are bound together into an organized and effective system of knowledge production. . . The result is that the research of every single person is based upon the knowledge of all, and that the judgement of every single person is conditioned by the judgement of others" (p. 40). According to T. Kuhn (1962), scientists share commitments, standards, laws, theories, applications and instrumentation, and take for granted first principles and justifications of concepts.

By continually using the expert scientist criteria to assess students' abilities in science, we create a deficit model of students and overlook the logic or reasoning they use, based upon their own knowledge and beliefs, in order to make sense of phenomena or solve problems. A useful direction for future research is an enquiry into the knowledge and intentions represented in students' investigations. A more appropriate metaphor for science educators is child as experimenter, inquirer or investigator. This study does not seek to show what students lack as compared with the "expert" scientist. Rather, this study seeks to explore the "child as experimenter." In this sense, the methods and procedures employed by children as they experiment will be regarded as legitimate and valid.

The Problem Statement

One leading direction of research in science education focuses on the nature of the learner (Linn, 1987). A widespread view that frames such research is that learners actively "construct" knowledge about the world around them from their physical and sociological interactions with their environment (Hawkins & Pea, 1987). Of the qualitative studies which examine student knowledge and beliefs, the majority use interviews or written questionnaires. Typically, students are asked for their predictions and explanations of a particular task or phenomenon. For example, in "Interview about Instances" (Gilbert, Watts & Osborne, 1985) students are shown drawings of phenomena on cards and asked a set of questions for each card. In "Demonstration Interview" (Goldberg & McDermott, 1983), students are shown a phenomenon using materials (e.g. filament lamp, lens and screen) and asked for predictions.

While there is a large body of research on students' "untutored" knowledge (Hills, 1989), few studies have examined the interplay between the students' knowledge and their actions in different contexts or settings (Clough & Driver, 1986). Few researchers have examined the knowledge students use in an action context, for example, as when students engage in designing, conducting and making conclusions about their own experiments. According to Klahr and Dunbar (1988), studies of scientific reasoning tend to minimize the "mutual influence of strategy and knowledge" (p. 7). Some investigators attempt to elicit students' strategies for formulating hypotheses, designing experiments and evaluating evidence. Others elicit students' knowledge about phenomena without regard for such issues. Klahr and Dunbar (1988) state that such a separation between knowledge and strategy is "highly artificial", and go on to say, "In any real scientific reasoning context, substantive knowledge and the form of investigative strategy are mutually influential, and the scientist's knowledge

about the topic influences the initial hypotheses, the types of experiments conducted, and the way results are analyzed" (p. 7).

Within the body of research which evaluates students' abilities in laboratory work, the majority use pencil and paper tests. Typically, the large number of students involved in such studies precludes any serious consideration of the individual action of students in investigating phenomena. According to Tamir (1990), "the practical mode is a unique mode of performance. Hence, there is no real and complete substitute for practical tests" (p. 243). Similarly, Bamberger (1988) makes a distinction between hands-on knowledge and symbolic knowledge by saying they are "equally powerful but different and not equally appreciated ways in which children and also adults organize and make sense of the worldly, everyday phenomena around them" (p. 2). She goes on to argue that some children are more expert at one way than the other. Tobin (1990) also acknowledges that students apply knowledge when doing science which they may not be able to reproduce on pencil and paper tests.

Large mandated studies assess students' performances of defined process skills (often in isolation) with the goal to establish norms across a large number of students. Such studies do not address the integration of these skills and the influence of knowledge, and cannot give detailed descriptions of children as inquirers.

It is clear that in order to evaluate students' abilities to perform laboratory work, researchers need to observe directly students in the laboratory setting. Hodson (1989) states, "Until we focus more sharply on what children are actually doing in the laboratory, we are unlikely to have a definitive answer to our questions about the pedagogic value of laboratory work" (p. 15). However, if researchers observe students during structured, recipe-type activities, they are more likely to find out how students follow directions than how they go about

investigating problems. Moreover, Woolnough and Allsop (1985) claim that school experiments that demonstrate a theory are not the same as problem solving investigations.

The purpose of this study is to explore young students' actions and the knowledge they use in an experimental context using an action theory perspective. The intent of such exploration is to characterize the experimenting capabilities of a sample of elementary students by exploring and documenting their actions as they conduct their own experiments during a goal oriented task. The role of the researcher is to establish the context and conditions which allow observation of students' actions while they are engaged in experimenting and to elicit students' reconstructions of their actions and knowledge of the materials. The Action Theory perspective by Argyris, Putnam and Smith (1985) was used to analyze the students' actions as they engaged in an investigation.

The study has three overall goals. First, it describes students' actions (e.g. use of materials, sequence of actions, data collection, making conclusions) and intentions as they work in pairs, during an experimental task. The intentions which underpin student actions were inferred from the researcher's observations, the students' talk to each other while experimenting, and their reconstructions of their actions. Second, the study describes the knowledge students use (as inferred by the researcher) as they experiment in order to elucidate ways the students frame the task, plan what to do, monitor what happens, and make conclusions. The third goal is to determine whether there might be developmental differences between intermediate elementary students. Students from grades 4 and 7 were chosen since they represent the first and last years of intermediate elementary school, thus providing greater possible variability.

Magnets were chosen for this study since most elementary students are familiar with ways in which magnets behave ("carry objects", "stick to things"). Students in a pilot study mentioned having magnets on their refrigerator at home, in toys, etc. Since one intention of this study is to compare grade 4 and 7 students, it was important to find a set of materials that was familiar to students of both grades. Also magnets are a topic in the elementary science curriculum. Currently, a minimal amount of research has documented students' understandings of magnets and their interactions with them.

The use of dyads in the study is a particular condition set to encourage students' conversation as a means to make students' thinking explicit. This dialogue helps inform the observer of student intentions "at the moment" without interruption and can be compared with students' subsequent verbal reconstructions of their actions. This approach is more appropriate (for young students) than the "think aloud" protocols which are more intrusive to the flow of action. Tobin (1990) argues that student collaboration "enables understandings to be clarified, elaborated, justified and evaluated. Time for reflective thinking is crucial, even when psychomotor skills are the main goal of the activity" (p. 407). Similarly, Wallace (cited in Solomon, 1988) when working with students in pairs and trios found that communication between students revealed: negotiated doing; removal of tension; partners giving help and tutoring; non-task talk; negotiated knowledge and constructed meaning.

In this study, the experiments performed by the student dyads were considered a joint activity. Wertsh (1980) makes a case for studying such cooperative activities as they are, to a large degree, what is "normally carried out in the real world." Moreover, in the case of the science classroom, students often work in groups because of the lack of materials. Fensham (1990) comments upon the use of small groups in laboratory work, "the use of scientific equipment and

materials in schools is expensive in capital outlay and maintenance and replacement. To reduce costs, most school systems organize students to do practical work in small groups rather than individuals" (p. 307). In some circumstances, teachers opt for group work as a deliberate strategy so that students learn about cooperation and negotiation.

Several months prior to this study, a pilot study was conducted involving six pairs of grade 7 students and two pairs of grade 4 students. In the pilot study some pairs of students were interviewed while watching the video of themselves experimenting, and others were interviewed without using the video (all pairs of students were videotaped while they experimented). It was found that the video provided an effective stimulus for students as they reflected upon their intentions and procedures of the experiments they designed and conducted. In addition, a means for systematic exploration of students' beliefs of magnetism (Event II) was added to the present study as a result of the pilot work. In Event II students worked with set of materials selected by the researcher.

The Choice of a Theoretical Perspective for the Study

In the realm of research, Harré (1986) contrasts an observer from an experimenter by saying that the observer stands outside the course of events in which he or she is interested in and waits for naturally occurring changes to study. He cites astronomers as the most perfect observers, since they cannot manipulate "the processes of the heavens" (p. 15). The experimenter, according to Harré, actively intervenes in the course of nature to study causal influences by separating and manipulating variables. In the real world, however, he states that there are few processes so simple that "they can be manipulated by one variable representing a cause and another its invariable effect" (p. 16). In the world of

human action, separating variables is not usually possible. Harré argues that such manipulation is not warranted;

> This is because attempts at isolation simply change or even destroy the property one wishes to study. For instance in social studies one must allow for the context within which a human action occurs, since how an action is interpreted is determined by its context, and the context in turn determines the effect it is likely to have. (p. 16)

He goes on to say that intervention in the natural world may lack the character of a "true" experiment but yields useful knowledge.

Taylor (cited in Argyris, et al., 1985) discusses the observer and the actor. He refers to the environment from the perspective of an actor as an "intentional environment." For the actor, the surrounding environment is more than a set of objects, it includes "situational cues" which evoke action (Jones & Nisbett, 1971). The "intentional environment" is meaningful also for those who observe the actions of others. Taylor explains that descriptions of actions must involve the intentions and beliefs of actors and the purposes of their actions. Without such information, for example, the same movement may occur in different actions, or the same actions may be carried out with different movements from the view of the observer. Harré (1986) also argues that an interpretation of action "is determined by its context" (p. 16). He uses the act of smiling as an example and says it can have different meanings depending on actions which precede and accompany it.

The present study investigates students' actions and intentions as integral components of goal-oriented tasks. The general approach described in Action Science by Argyris, et al. (1985) is used as a framework for the overall design of

the study. Action science is a systematic enquiry into the ways in which people design and implement action. The overall goals are: to contribute knowledge to a general action theory and to solve practical problems which involve human action in a practical setting. Action science researchers design methods which provide insights into individual acts and underlying intentions at the time. From the data, the researcher constructs propositions based on inferences and observations. Researchers also create conditions for potential disconfirmation of these propositions via interviews, participant-written cases, or intervention activity. Action Theory (Argyris, et al., 1985) is used as a theoretical perspective for making sense of the students' actions in the study (see Chapter 2).

The present study generates knowledge that is: useful to the practice of science teaching; descriptive in its in-depth approach; valid by providing evidence of what elementary students can actually do in a particular experimental setting; and informative about change by studying what could be implemented in laboratory activities (should students be encouraged to plan and design their own experiments?). The generation of such knowledge outlined above are similar to the purposes of Action Science. This perspective was chosen for the present study for the following reasons. The first two relate to science education in general, and the remainder to the purpose, methods and analysis of the study.

1. Action science generates knowledge for both researcher and practitioner and maintains a link between theory and practice since theory can inform practice and practice can inform theory. Problems which are investigated by the researcher are problems related to practice.

2. Action science researchers attempt to create alternative possibilities to the status quo. For example, what are alternatives to current practices of student laboratory activities?

3. Action science emphasizes the intentions and meanings of actions. According to Argyris, et al. (1985) "human beings are designers of action. To see human behaviour under the aspect of action is to see it as constituted by the meanings and intentions of agents [actors]" (p. 80).

4. The role of the researcher as observer and interventionist is well defined. The researcher creates conditions for both observations and possible disconfirmation of inferences via interviews, intervention activities, or participant-written cases.

5. Action science focuses on cognitive processes involved in action. The authors state, "Designing action requires that agents construct a simplified representation of the environment and a manageable set of causal theories that prescribe how to achieve the intended consequences" (p. 81).

Research Questions

The three research questions of the present study enquire into students' actions and knowledge as they design and perform experiments in order to answer an operational question, "Which magnet is strongest?" when given a set of three magnets.

Set 1 questions focus upon the knowledge and beliefs students use while planning, conducting and evaluating their experiments.

1. What knowledge do the students appear to use in the action context?

1a. What knowledge of magnets can be inferred from students' use of materials?

1b. What knowledge of experimenting can be inferred from students' sequences of actions?

1c. What knowledge of magnets and experimenting is elicited during students' reflections about their actions?

Set 2 questions direct attention to the influence of the operational question on how students use materials and their sequences of actions from the time they begin experimenting until they state a conclusion.

2. What are students' actions in response to an operational question (Which magnet is strongest?) with a given set of materials?

2a. What theories-in-use can be inferred from students' actions and their reflections of their actions?

2b. What are the sequences of students' actions?

2c. How do students reach a conclusion?

Set 3 questions deal with the comparative component of the study. Students from grades 4 and 7 are represented in the study.

3. How do the actions and knowledge of students from grade 4 compare with students from grade 7 during the task?

3a. How does student knowledge of materials and their interactions with materials compare?

3b. How do their sequences of actions compare?

Significance of the Study

This study extends the existing research on the nature of the learner as he or she engages with materials. In discussing future research in science education, Linn (1987) states, "Researchers need to explore in greater detail such questions as how students develop a world view, reason about new information, and solve problems in science" (p.209). Hegarty-Hazel (1990) argues that a better

understanding of how laboratory experiments influence the learning of scientific knowledge would help teachers achieve learning outcomes. The present study fits within the current scope of research on the learner and presents a case for what students do with materials when given an operational question. The study focuses specifically on the nature of the learner by examining the learners' intentions and knowledge while experimenting.

The study also adds to the empirical data base on students' conceptions of topics in science. Students' ideas about magnets have been studied minimally. This researcher inferred students' knowledge about magnets from their actions and reconstructions of their actions which proved to be a viable method for eliciting student knowledge.

The study will be useful for educators in determining reasonable expectations of grade 4 and 7 students' abilities to carry out experiments when given familiar materials and an operational question. It addresses the question, Do grade 4 and 7 students require a recipe to do experiments? Can they design their own experiments? Also, conclusions from the study will be informative to teachers who use hands-on activities as a component of student assessment in their classroom.

Delimitations of the Study

This case study is exploratory in nature and attempts to answer, in the broad sense, "What is the case?" when students are given a specific operational question and a set of materials. It will be placed in the contextual tradition which focuses, in depth, "an inquiry around an instance" (Adelman, Jenkins & Kemmis, 1976).

The particular "instance in action" in this study is bound by the following conditions. The students involved in the study came from one elementary

school, which is located in a middle to upper-middle socio-economic neighbourhood. Student dyads were chosen by the classroom teacher from specific criteria, supplied by the researcher. The sample comprised four dyads each from grades 4 and 7. This sample is small in number and does not represent students in general from these grades levels. The materials themselves and the operational question given to the students also dictate the boundaries of the study. Knowledge claims are made within these boundary conditions and are based on the researcher's inferences. The study does not attempt to generate a 'grand' theory; rather it develops conjectures about elementary students' abilities to design and conduct experiments. Further, it outlines a methodology for examining students' experimenting.

CHAPTER 2

Knowledge and Action

Introduction

The purpose of this study is to explore and document students' actions and the knowledge they use while experimenting. This researcher agrees with Klahr and Dunbar (1989) who argue that in any investigation the knowledge held by the investigator influences the hypotheses generated, the types of experiments conducted, and the interpretation of results. Following this view, the present study examines the students' knowledge and beliefs about magnets in order to gain insights into how they frame the task, plan experiments, monitor what happens during the experiments, and make conclusions. For the researcher, such insights are useful prerequisites for making sense of students' actions during the task. Thus, this researcher emphasizes the cognitive nature of action, and views student action in the study as goal directed and purposeful.

Chapter 1 discussed the general problem area which this study addresses, the role of student laboratory work within Science Education literature. This chapter focuses on two general theoretical frames germane to this study.

Perspectives on the construction and organization of knowledge. These perspectives include sections on cognitive development (Piaget), "critical barriers", alternative frameworks, and novice/expert studies. The sections on schemata, personal theories and models (including causation models) are more general in nature and complement the following section on Action Theory.

Theoretical perspectives of the study (from Action Science). This section describes Action Theory and how it is used in the study.

Perspectives on the Construction and Organization of Knowledge

The "untutored" knowledge (Hills, 1989) that students bring to science lessons has been a focus of science education research for over a decade. Driving this research is a widespread view among science educators that students are not passive receivers but active constructors of knowledge about phenomena from their interactions with the environment (Driver, 1981; Tobin, 1990; Hawkins & Pea, 1987; Osborne & Wittrock, 1985). This view falls within a broader theory of knowledge called constructivism. According to von Glassersfeld (1987), the two principles of constructivism are (1) knowledge is not passively received but actively built up by the cognizing subject; (2) the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality. He adds that accepting only the first principle, as some science educators may, is considered "trivial constructivism." Robert Kegan (1982) speaks of the latter principle as he proposes, "We constitute reality, rather than somehow happen upon it... behind the form (or thing) there exists a process which creates it, or which leads to its coming into being..." (p. 9). This process or activity Kegan refers to are an individual's construction and organization of meaningful representations and interpretations of objects and phenomena of the surrounding environment.

Piaget

The notion of cognitive construction is a major component of Piaget's developmental theory which attends to the development (i.e. cognitive stages) of the meaning-constructing activity (Kegan, 1982; Millar & Driver, 1987; von Glassersfeld, 1987). His writings in this area span several decades, and his methodologies have influenced science education research (Osborne & Wittrock, 1985; Linn, 1987) as well as science curricula. According to Driver (1981),

> The work of Jean Piaget and others on the development of children's thinking has indicated that far from being the 'tabula rasa' of repute, pupils bring to their school learning in science ideas, expectations and beliefs concerning natural phenomena which they have developed to make sense of their own past experiences. (p. 93)

Piaget's theory of development includes a sequence of cognitive stages through which an individual develops, from infancy to adolescence (i.e. sensorimotor, preoperational, concrete operational and formal operational). Stages are characterized by "psychological functioning" which differ qualitatively from each other (Shuell, 1990, p. 532). Individuals in the same stage share a logic and consistency (Kegan, 1982) as they construct meaning of the physical world. For example, the five-year-old child (preoperational stage) uses perceptions in her organization of the world whereby the meaning of a particular event is embedded in and subject to perceptions. In a task, for instance, where the same liquid is poured into a tall thin container and into a short wide container, this child will tell us that the taller container has more water. The ten-year-old child (concrete operational stage), however, sees the two containers as holding the same amount of water This child is able to conserve the quantity of liquid by arguing for the "reversibility of the process" and hence is able to both coordinate and reflect upon her perceptions. In the realm of experimenting, the concrete thinker can recognize physical properties of objects as variables (Linn & Thier, 1975). While the ten-year-old thinks in terms of 'what is', the adolescent (formal operational stage) constructs meaning subject to the hypothetico-deductive, 'what could be' and coordinates "second order operations" (operates on concrete operations) (Kuhn, 1989). Formal thought "is characterized by a reversal of the importance of

'reality' and 'possibility' in the subjects' approach to a problem" (Linn & Thier, 1975, p. 50). The formal thinker can design many experiments to show relationships between variables.

Piaget's work on how children develop conscious awareness of their actions is pertinent to this study. In an action setting, although young children are able to perform a task they may not be aware of how they 'went about' doing it. Karmiloff-Smith and Inhelder (1974, p. 210) argue that "although the child's action sequence bears eloquent witness to a theory in action implicit in his behaviour, this should not be taken as a capacity to conceptualize explicitly on what he is doing and why." The authors cite Piaget's work as showing that "a developmental gap exists between succeeding in action and being capable of explaining it" (p. 209).

'Knowing how' is a domain of knowing that is reflexive and intuitive, and orientated towards the success or failure of achieving a goal. Awareness or cognizance of action involves conceptualization. According to Piaget reflective consciousness of actions "is not simply a matter of throwing light on ones' own actions (or thoughts) and passively viewing what is thereby revealed. Rather it involves active conceptualization..." (Chapman, 1988, p. 287). Piaget (1976) explains such conceptualization,

> The subject looks at his actions and these are assimilated, more or less adequately, by his consciousness as if they were ordinary material links situated in objects - hence the necessity for a new conceptual construction to account for them....Furthermore, it presents the same risks of omissions and distortions as if the subject were required to explain to himself an external system of physical connections. (p. 339)

Piaget's conclusions are based on his experiments with children where they are asked to perform a task (and pay attention to what they are doing), such as throwing a sling at a target. Afterwards they are asked to explain their actions. Although young children could perform tasks with practice they did not explain what is observable in their own actions. In the case of the sling, the young child knows "how to" hit the target but usually claims he released it opposite the target, which is not in fact the case. Children distort what they observe. According to Piaget (1976),

> It is not, therefore, simply a case of the child's predicting what will happen -in other words, making an inference before actually seeing what happens. He really sees something, but his observation is distorted by an inference, which is something quite different. (p. 337)

Piaget distinguished general levels in the development of reflective consciousness: knowledge of the material action (the child can do the action but not explain it), the conceptualization of action, and finally, reflective consciousness of action (Chapman, 1988).

"Critical barriers"

While Piaget's work influenced earlier research in science education, more recent research (particularly in the 1980's) has focussed on the content of students' thinking in specific content domains (Hills, 1989), establishing a rich repertoire of student beliefs on science topics. Linn (1987) reports, "In recent years, researchers have studied the mechanisms students evoke and the frameworks or models they construct to explain events in specific domains" (p. 196).

Within this repertoire of studies, researchers report that student beliefs are tenacious since they have consistently "worked" for students in their everyday activities, and are often at odds with canonical science (Hawkins & Pea, 1987). Thus, research shows a chasm between "the constructs of students' everyday experiences" (Osborne & Bell, 1985) and abstract scientific concepts. David Hawkins (1978) first used the term "critical barriers" to describe a class of perceptual commonsense approaches to elementary science topics (e.g. mirrors, heat, mechanics) which he believed become barriers to students learning scientific concepts. He asserts that principles underlying science lessons are "unobvious to those who have not yet assimilated them" (p. 4).

Today, science educators view student "prior knowledge" as a critical component of new learning experiences (Hewson & Hewson, 1988; Tobin, 1990). Linn (1987) states,

> The new consensus about the learner places greater importance on what the learner already knows and what the student can learn. One major implication for teaching strategy which emerges from our better understanding of the learner is that it is inappropriate to assume the students simply absorb information. Rather, it appears that students constantly interpret new information based on their particular world view. (p. 197)

Piaget introduced the terms assimilation and accommodation in a similar sense, where in the former learning is incorporated into prior knowledge and the latter learning modifies prior knowledge (Garrison & Bentley, 1990).

Solomon (1988) argues that the human mind cannot be 'rubberstamped' with new ideas, rather people "incorporate" ideas into existing schemes. Likewise,

Carey (1986) speaks of "integrating" new information into already existing knowledge or schemes. The notion of schemes (or schemata) or scripts comes from a cognitive model that explains that information is stored and interrelated in our memory in various forms (i.e. knowledge about specific phenomena or complex reasoning structures) and influences the way we interact with the environment (Millar & Driver, 1987). Rowell and Dawson (1989) refer to schemata as "functional units of related information" such as an organized body of inferences. Schemes are existing knowledge structures that, when activated, provide a framework for comprehension of situations (Carey, 1986).

The type of comprehension, referred to by Carey, applies to students making sense of experimental tasks (i.e. the problem) in which they engage. According to Millar and Driver (1987), "Children may appear to fail to undertake an experimental task correctly, not because they lack an appreciation of the notion for a 'fair test' or the need to control variables, but because the task as presented does not reflect the way they are conceptualizing the situation" (p. 50). Making sense of the task involves the selection of what students believe to be relevant features and objects (including materials) and constructing a coherent frame that informs perceptions and interpretations. Woolnough and Allsop (1985) argue, "The things they look for, the perceptions of what they see are determined by the cognitive framework that they bring to the observing...Those preconceptions which students bring with them into the laboratory determine how they perceive experimental data" (p. 36). Similarly, Millar and Driver (1987) conclude, "In more complex tasks, such as designing an experiment, what a learner does depends not only on the features of the task but on the conceptual scheme used in the situation" (p. 46).

The notion of "partisan experimenter" (Solomon, 1988) applies also to the scientist as Harré (1986) points out, "Without some prior idea of what might be there to be found out we would not know what to look for in the results of our experiments, nor would we be able to recognize it when we had found it" (p. 5). Prior ideas become "critical barriers" when student observations do not match up with the intended learning outcomes of the lesson.

Novice to Expert

diSessa (1983) conjectures that at the root of many student explanations and justifications are simple knowledge structures, like axioms, which he calls "phenomenological primitives" (p-prims). P-prims "are monolithic in the sense that they are evoked as a whole and their meanings, when evoked, are relatively independent of context" (p. 15). diSessa has explored the evolution and functions of P-prims in physics understanding from novice to expert.

He explains that scientific explanation begins with common sense observation of what appears to be isolated cases. What follows is sifting through cases and finding more general and fundamental ones that serve as principles. Similarly, in learning physics, novices begin with a host of recognizable phenomena (p-prims) which allow them to see the world in particular ways. Some p-prims are compatible with physics and serve "cognitive functions in a physicist's knowing physics" (p. 17). Others are abandoned (in the move from novice to expert) for more fundamental ideas which have a higher priority. For example, rigidity (hard objects are rigid) is a p-prim that the physicist may abandon for springiness which is "a more powerful explanatory concept" (but also has limits). A more powerful encompassing concept is more efficient than situation-specific reasoning.

diSessa states, "[There exists] a difference between novices and experts, indeed between common sense and scientific reasoning, which is not so much the character or even content of knowledge, but rather its organization. Experts have a vastly deeper and more complex priority system" (p. 32). According to diSessa a priority system consists of the "cueing priority" and the "reliability priority." The former refers to how profitable an idea is to the situation (one idea may have a higher cueing priority in a particular context). The reliability priority has to do with the resistance (of whatever is cued) to abandonment, for a more fundamental idea. The priorities are therefore context-dependent. The expert, as compared to the novice, has a large set of contexts that cue an idea with different priority systems. That is why diSessa speaks of the movement from novice to expert as a reorganization of priorities.

Garrison and Bentley (1990) discuss two different views of conceptual development in science (from novice to expert). Weak restructuring involves the number and relationship between concepts and the organization of knowledge in terms of schema, where the expert uses abstract schemata that "do not exist or are not readily accessible to the novice" (p. 21). The authors argue that, "In many ways it is the domain specific equivalent of Piaget's idea of assimilation." In radical restructuring, it is not that the novice has an incomplete schema compared to the expert, but may hold an entirely different, "alternate" one which has different concepts and relations and may cover a different range of phenomena. This view may account for the difficulties students have in learning science. Garrison and Bentley argue that radical restructuring resembles Piaget's notion of accommodation.

Alternative Frameworks

What many researchers seek to explain is the source of student difficulties in learning science. As Garrison and Bentley point out, the tension that occurs between student "prior knowledge" and scientific concepts may account for some difficulties.

Driver (1981) has used the term "alternative framework" to describe beliefs or expectations that students hold that differ from the currently accepted (scientific) view. Hills (1989) interprets Driver's meaning of this term and suggests that alternative frameworks "emerge on their own, as it were, in the absence of any traffic with currently accepted scientific ideas and explanations" (p. 165). McClelland (1984) states that a framework consists of "interlocking concepts unifying more that one set of phenomena" and an "alternative framework" is one that differs from accepted scientific explanations (p. 1). He argues, however, that science is the result of a conscious theorizing. Student ideas associated with phenomena are not necessarily scientific, otherwise there is no way of conceiving what is not scientific. It appears that McClelland's point is that children's ideas are often not comparable to scientific concepts and therefore should not be termed "alternative."

Within the literature, Hills (1989) uncovered a variety of terms used by science educators that represent student beliefs of natural phenomena. While some researchers use the term misconceptions, others are more comfortable using less negative terms such as alternative framework or children's science. According to Hills, underlying most of terms representing student beliefs is "the assumption that the untutored views youngsters bring to science instruction can be interpreted as scientific - at least in some embryonic sense" (p. 157). That is, student beliefs are thought to be false or defective, a misunderstanding, or a limited version of the scientific view. Like Millar and Driver (1987), Hills argues

that young students may operate "under the auspices of some alternative to the scientific framework" (p. 165).

In an attempt to better understand children's "untutored" beliefs about phenomena, and not simply compare them to expert beliefs, Hills (1989) proposes we think about children's beliefs from a commonsense framework. He defines commonsense as shared concepts, beliefs and values of people that "provide a basic view of the world, of their position in the world, and how they ought to act" (p. 169). Rather than thinking of commonsense as isolated ideas or rules, he argues that commonsense can be viewed as a system or framework that people of the same culture use in their daily activities and is based partly on a common language. Hills argues further (based on previous arguments made by Churchland, 1979) that this framework can be regarded as a theory or battery of related theories, since commonsense exhibits generality, consistency and testability, as well as predictive and explanatory power.

Similarly, Viennot (1979) studied students' predictions and explanations of the relations between force, energy and motion and argued that students share a common and consistent way of explaining what she calls "intuitive physics" or "spontaneous reasoning." Such reasoning consists of a set of self-consistent concepts found in "everyday conversation and much that one reads; so much so that every one of us does, from time to time, reason in this way or, at least has done so" (p. 205).

Personal Theories

Much like Hawkins' (1978) class of "critical barriers", recent research shows communalities across different students' ideas and a consistency within individual students (Hewson & Hewson 1988), suggesting that student knowledge develops in common ways or from a common body of experience and

observation (Hodson, 1986; Linn, Pulos, Clement, & Sullivan, 1989). Claxton (1982), using assumptions laid out by George Kelly, posits that our interactions with the physical world are mediated by our "personal theories." Personal theories come from our direct experience and consist of a set of predictions, actions, descriptions and explanations. The consequences of actions are the data that inform us about the boundaries of a theory "if the theory copes successfully with such an event, then the specification of its domain of experiences is altered to include it" (Claxton, 1982, p. 3). Failure to predict or explain some event usually xresults in an extension, modification or abandonment of a theory. Personal theories inform us about what to expect in situations and what to do in order to bring about particular consequences. He argues that personal theories often operate in an unconscious way and without being "understood", especially with young children. Children usually have a host of personal theories, or mini-theories defined by situations, or domains of experiences in which they apply. He states, "Each mini-theory is born out of the need to make sense of, and act effectively within, a new type of situation" (p. 3). According to Claxton, mini-theories are activated by a specific set of situations which result in particular predictions and actions.

Mental Models

Norman (1983) argues that people make sense of some phenomena by constructing mental models within specific domains through their interactions with the environment. In this case, a mental model represents a person's beliefs about a physical system based upon their observations and inferences. An intrinsic characteristic of mental models is that they are functional representations we use to gain understanding and make predictions. Norman refers to mental models as naturally evolving models of target systems (a system

which a person is using or learning) in our heads which are continually modified "in order to get a workable result" (p. 7). In this sense, they are incomplete since new information from the environment or predictions which do not 'work' may lead to modification. Norman goes on to say that mental models are constrained by a person's previous knowledge and experience. He concludes that they are: incomplete, unstable; without firm boundaries, often unscientific (even superstitious), and parsimonious.

Gauld (1989), for example, discusses children's models of electricity, "...children learning about electricity for the first time possess a variety of models about the nature of electric current in a simple electric circuit consisting of a battery, a lamp and wires" (p. 63). Students use the terms "electricity", "energy" and "power" as equivalent terms while talking about what happens in an electric circuit. He outlines the following four models that children display:

Model A: A *consumption* model in which 'electricity' emerges from one end of the battery and is all consumed by the lamp which lights up.

Model B: A *reaction* model in which two types of 'electricity' emerge from the battery - one from each end - and react in the lamp to make it glow.

Model C: A *consumption* model in which some of the 'electricity' which emerges from one end of the battery is consumed in the lamp which lights up while the rest of the electricity returns to the other end of the battery.

Model D: A *squeezing* model in which all of the 'electricity' emerging for one end of the battery squeezes through the thin wire in the lamp filament causing it to glow and then returns to the other end of the battery.

Mental models are similar in nature to personal theories in that they cover specific domains and are based upon an individual's interactions with the environment.

A Model of Causation

Andersson (1986) argues that there is a common core, or set of elements, to students' explanations and predictions of phenomena in a wide range of science topics such as heat and temperature, electricity, optics and mechanics. He calls this common core the Experiential Gestalt Causation (EGC). It involves the interaction (direct physical contact) between an agent, the instrument and the object which is experienced as a gestalt (their occurrence together is significant). According to Andersson, "we use the experiential gestalt causality all the time to control our actions and to comprehend what is happening in the world around us" (p. 157). Examples of EGC are causal generalizations individuals make from many of their experiences in the physical world. For instance, the greater the effort, the greater the effect (an example of EGC) may translate to a situation such as the harder a ball is thrown, the further it goes. The agent is not necessarily a person but could be an object in motion or an object exerting a force. For example, in the case where A is the agent, and O is the object, A exerts a force on O and O moves. Based on a person's experience, the more force exerted by A, the greater is the effect on O.

In the elementary science classroom, many children predict that a heavier steel ball dropped into a container of water displaces more water than a aluminum ball of the same volume. In this case, the ball is the agent that causes the water (object) to rise. The child's experience of how heavy and light objects behave may tell her that the increased weight of the steel ball gives an increased effect or makes the water rise more. Another application of a child's EGC involves distance. There may be situations where the effect on the object increases (or decreases) as a function of distance between the agent and the object. For example, the closer a person comes to a fire, the warmer it feels. Andersson (1986) uses the example of a magnet, where it attracts paper clips more strongly, the nearer it is to the object.

Some abstract concepts in science do not correspond to what a child experiences in everyday life, such as motion without observable forces. This becomes problematic for students who have used the above type Experiential Gestalt Causation to successfully organize their previous experience. Also, many scientific models, although they too are models of causal thinking, go beyond what is observed and include concepts such as light rays, atoms and magnetic fields. According to Andersson (1986), "We attribute properties to these non-observables, for example, 'the atoms (molecules) in a gas move about independently of one another with high speed' or 'light propagates in straight lines'" (p. 168).

Benbow (1988) worked with grade one students who were exploring magnets and found that many believed that the size of the magnet was an indicator of magnetic strength. She argues, in light of this conclusion and other similar findings in the literature, there are a class of science 'misconceptions' where students equate magnitudes of related observable to non-observable components of phenomena. In the case of magnetism, a large magnet

(observable) means a large amount of strength (unobservable). Other examples within this class of beliefs include: when an object is further from the ground, the force of gravity is stronger; a larger object has more weight.

Student models of causation as described by both Andersson (1986) and Benbow (1988) are central to students' predictions. Argyris, et al. (1985) argue that in action people select causal theories constructed from experience that can be applied to situations and prescribe what to do to achieve intended outcomes. Predictions are an integral part of causal theories in that individuals predict what will happen following particular actions. Causal theories and action are discussed in the following section.

Theoretical Perspective of the Study

According to Argyris, et al. (1985) "They [actors] make sense of their environment by constructing meanings to which they attend, and these constructions in turn guide action" (p. 81). The constructions of meanings are based on the actor's knowledge (repertoire of schemes or "causal theories") that "serves to inform action." Therefore, we may think of knowledge as a mediator between the environment and action (to prescribe 'how to'). In this sense, knowledge is an implicit part of action. Claxton (1982) writes, "All our dealings with the physical world... are mediated by a theory that has arisen partly from direct experience and partly from informal intuition" (p. 2). The following section describes Action Theory from Action Science by Argyris, et al. (1985) and shows how Action Theory is a useful lens to view the 'child as experimenter.'

Action Theory

In the action context, people cannot attend to all the information from the surrounding environment and must select features from the setting relevant to

the purpose or problem at hand (i.e. how to achieve intended consequences). To Argyris, et al., (1985) problem setting is described as the process of directing our attention and selecting meaningful features or objects and their suitable connection or frame. The framing of a situation in light of a problem distinguishes possible action strategies we can implement and how to interpret the consequences of our actions.

In the present study, elements of problem setting are particularly relevant to the researcher. The way students frame the task in response to the operational question, "Which magnet is strongest?" may vary. In particular, the notion of strength as it is applied to magnets may mean different things to different students. One way to infer how students interpret the operational question is to examine students' reflections upon their conclusions. For example, one conclusion may be, "Magnet A is the strongest because it holds more objects than the other magnets." In this instance, "holds more" provides a clue as to the meaning ascribed to the word "strong." Also, "more objects" indicates how the magnets were compared.

In the action context, people also select a manageable set of causal theories (If I do *a*, then *b* will occur) which can be applied to the situation and inform us 'how to' achieve the intended consequences. These causal theories are sometimes called schemata, scripts or patterns, which we have constructed from our experiences. It is more efficient, in action, to draw from a repertoire of causal theories we have learned than to construct new ones for every situation we encounter. An example of a causal theory is, a magnet will pull metal objects at close range.

Causal theories may also be thought of as tacit rules or hypotheses embedded in actions (e.g. If I place the magnet close to a metal object, the magnet will pull it). Such tacit rules often become explicit when we encounter a

consequence which is unexpected or disconfirms our hypothesis. For instance, when we touch a magnet to an aluminum object and it is not attracted to the magnet, we reflect (consciously) on our hypothesis. Also, we may reflect on these hypotheses when they act as probes in novel situations (will a magnet pull a penny?). In an unfamiliar situation, monitoring the consequences of our actions generates information about the suitability of the original framing. An individual frames a situation and modifies it according to particular consequences (a magnet will not pull some metal objects).

In this study, dyads were asked to work cooperatively to encourage talking aloud and making explicit what they are thinking as they planned their experiments. Working together requires students to communicate to each other what to do, what materials to use and how to interpret the consequences of an experiment. A partnership also establishes a means of sharing surprises such as unexpected effects and information from exploratory actions.

In action science, theories of action are defined as a set of complexly related propositions or "design programs" which guide an actor's selection of representations of the action setting and causal theories to achieve intended consequences. The form of such a proposition (for the actor) would be, "If I act in this way under these circumstances, then I can expect the following consequences." Another way is to say, "in situation S, to achieve consequence C, do action A." From the perspective of the actor, it is what he or she should do to achieve certain results, and is referred to as a theory of control. To the observer, however, a theory of action is an inferred explanation or prediction where the researcher asserts that the individual is using a rule or hypothesis to guide his or her actions. Hence, for the observer a theory of action can be understood as a theory of control held by the actor.

Argyris, et al. (1985) distinguish two kinds of theories of action. Espoused theories are explicit theories which people communicate to others. They are the theories that people claim to follow. In the present study, for example, students' reflections (spoken) of what they did to find the strongest magnet are their espoused theories. A student may say for instance, "We were seeing how far the magnet was from the washer before it pulled it." Theories-in-use are inferred from what people actually do (rather than what they say they do). In this study, theories-in-use are statements constructed by the researcher that infer students' tacit rules or hypotheses prescribing or directing the observed action (e.g. 'how to' find the strongest magnet). One example is, "the strongest magnet will attract magnetic objects from a greater distance." In this instance, a student holds a magnet over an object, lowers the magnet to the object until it is affected by the magnet and measures the distance between the object and the magnet. The distances are compared after using all three magnets, and the magnet which corresponds to the largest measurement is said to be the strongest.

There may be discrepancies between what people say and what they do. Therefore, our espoused theory may be inconsistent with the theory-in-use. In this study, theories-in-use were inferred from two sources, observations of students' actions, and their talk in action (a dyad's conversation as they experiment). In action science, talk within the action context is regarded as an important form of action. For example, one student might say to the other, "Let's see how far away this magnet is until it *pulls* the washer." These three data sources, observations, dyadic talk and student reflections, provided three windows on student action, a triangulation, for comparison.

The inclusion of problem setting makes Action Theory a powerful perspective for this study. This perspective is a contrast to many studies which focus only on means-ends deliberations of solving the problem presented in the

task. By investigating how students frame (as Carey, 1986 says, "comprehend") the task, the researcher gains insights into student interpretation and evaluation of their experiments. By following student conclusions and evaluations, the researcher obtains clues as to what students expected to happen as a result of actions during experiments (were their expectations met?). This study therefore adds to research that investigates the influence of students' "untutored" knowledge (Hills, 1989) on their experimental designs.

CHAPTER 3

Methodology and Analysis

Methodology of the Present Study

This thesis is in the qualitative, interpretive enquiry tradition (Soltis, 1984). The conditions established for gathering data were three events in which eight student dyads participated (see Table 1). For Event I, the researcher presented dyads with an operational question (Which magnet is strongest?), two sets of magnets (Set 1 and Set 2), one set at a time, and a box of magnetic and non-magnetic objects. The researcher observed and videotaped the students' actions with materials until they arrived at a conclusion for both Set 1 and Set 2 magnets. For Event II, the researcher presented dyads with a new, small set of objects, specially selected to explore students' understandings of magnetism. Students were asked to use these objects to show the strongest magnet, again using Set 2 magnets. The researcher conducted an informal interview while students manipulated materials. During Event III, the researcher interviewed dyads while they watched the video of themselves experimenting during Events I and II.

The Students.

Eight grade 4 students and eight grade 7 students participated in the study. In the sample, each grade level had an equal number of boys and girls. These students came from multi-grade classrooms. Students were selected and paired by their teacher using criteria provided by the researcher. These were that students should be articulate and able to work cooperatively; and that they had maintained average to above average performance in school work. Each teacher paired such students, boys with boys and girls with girls, who were compatible

and friendly. From previous work with dyads, this researcher found that adolescent dyads of mixed gender often do not communicate well or work cooperatively. Also, some studies show that boys tend to dominate interactions with equipment during laboratory activities (Tobin 1990).

Table 1

Components of the study

Day	Event	Materials	Procedures
1	Event I	Set 1 magnets Set 2 magnets Box of materials	The experimenting task
1	Event II	Set 2 magnets Specialty materials	Use of specialty materials with interview
2	Event III	----	Interview using videotape of Events I and II

In this study, the students' names have been changed for reporting purposes. The names presented are followed by a 4 or 7 representing their grade level. The study presents eight separate cases.

The School and Setting.

The elementary school which provided the students and setting for the study has some 375 students in kindergarten through grade 7 (14 classes). About three-quarters of the students live in a university housing community where at least one of their parents is a full time student. One-quarter of these students come from a country other than Canada.

The school has adopted a policy of multiple-age grouping due to the transient nature of the student body (the majority remain at the school only as long as a parent attends the university). Multiple-age grouping means that students usually stay with the same teacher for three years. It is the staff's opinion that stable social grouping is important to students who are in Vancouver temporarily, and who may have a different cultural background. The staff believes grouping enhances the teacher-student and student-student relationships. The student body displays a feeling of cooperation where older students help the younger ones within the same class. Both the teachers and the principal were cooperative and interested in the study.

For the events of the study, one student dyad and the researcher worked in a multi-purpose room at the school site for two mornings. Each week the researcher worked with a different dyad. The room is located in the basement of the school and is used occasionally for music and other classroom related activities.

Materials.

Students were asked to find which of three magnets is strongest in each of two sets of magnets. The magnets were specially constructed for this study (see Appendix A). Set 1 magnets were different physical sizes, weights and strengths, and the heaviest and largest magnet was also the strongest. Set 2 magnets were different sizes, weights and strengths, and the smallest magnet (not the heaviest) was the strongest (The strongest magnets for each set were constructed with the largest number of ceramic magnets). In Set 2 magnets, one magnet was large and also light in weight. The purpose of using two magnet sets was to examine students' experiments when the strongest magnet is largest in one case and smallest in another. Also, other data generated from students' experimenting

(e.g. theories-in-use, sequences of action) with Set 1 magnets was compared with Set 2 magnets.

Each magnet was a composite of rectangular ceramic magnets, or ceramic magnets and wood to alter the size. Where necessary, lead shot was inserted in the wood section to produce a particular weight. All the magnets were covered with paper to disguise their composite constructions and painted red, green or black in order to be recognized easily on video tape. The three magnets in each set were labelled A, B and C in white letters.

In addition to the magnets, in Event I, each dyad was provided with a box containing a variety of objects such as paper clips, nails, washers, plastic squares, ruler (see Appendix B). Similar objects of different sizes and weights (e.g. small and large steel balls) were included. Students were told they could use any of these objects to find the strongest magnet but they did not need to use all the materials.

During Event II, students were provided with a new set of objects and Set 2 magnets (so students were familiar with the magnet set). The set of objects included two flat sheets of metal (16cm x 10cm), one piece of wood (8cm x 8cm x 1.5cm), one piece of plastic (8cm x 8cm x .5cm) with twelve holes drilled through the plastic, and a small steel cube. The purpose of presenting these materials was to elicit and explore student understandings of magnets with materials designed and selected from pilot work. The plastic square was meant to explore students' thinking about how the holes in the plastic may affect the interaction between the magnet and magnetic object (cube or iron sheet) when the plastic is placed between the two. In pilot work, students used nonmagnetic materials as a barrier to "block" or "dilute" a magnetic field, or what they called rays or chemicals, "coming from the magnet." The metal sheet adheres to the magnet but other steel objects do not adhere to the sheets when it touches the magnet. (This

metal is used as magnet guards.) The researcher was interested in how students would explain this outcome (when the metal sheet is between the magnet and cube). In pilot work, students often chained magnetic objects and talked about the magnetic field "travelling" through metal objects. The wood was included with these materials to explore students generalizations of the notion of 'barrier' to different non-magnetic materials.

The Events

Data were collected from the following three events.

Event I. The Experimenting Tasks. The purpose of this event was to set specific conditions for students' actions to take place, and for the researcher to observe, document, and make inferences about these actions. The operational question and materials presented to dyads created the context for experimenting. The talk between dyads, as they experimented, was regarded as an important form of action (see Appendix C for an example of a transcript of Event I and II). In pilot work for this study dyads' conversations provided many insights into students' actions and conclusions including the suggestions made to each other of what to try, instructions about procedures, and discussion about a final conclusion.

Before dyads began the task the researcher showed them Set 1 magnets and encouraged them to examine the materials in the box. Each pair was told they could use any of the materials but they need not use all of them. Students were asked to work cooperatively and to tell the researcher when they reached a conclusion for a magnet set. Also, the researcher told the dyads there was no time limit, and when they concluded which magnet was strongest in Set 1, they would be given Set 2 magnets and the same materials. During this event, the researcher observed and made field notes of dyads' actions.

Event II. The Use of Specialty Materials. When the students reached a conclusion for Set 2 magnets, the researcher presented them with the the specialty materials and Set 2 magnets again and asked, "Can you use these materials to show which magnet is strongest?" After students worked for about five minutes, the researcher intervened, by asking questions about the effects of placing particular objects between the magnet and steel cube, and asking students to try it.

The proceedings for Event 1 and II were videotaped from about five meters away using a telephoto lens. The camera sat on a tripod. Two flat microphones were placed on the table in front of the students as they worked. One microphone was connected to the video camera and the other to an audio tape recorder (as a back-up). Students were told of the location of the video camera and microphones before they began to work. Event I and II took about one hour for each dyad.

Event III. The Interview using the video. The use of video is one way that actions are 'fixed' for subject and researcher. The purpose of using the video during an interview is to "slow down [by starting and stopping video] the actions so that actors can reflect on the tacit understandings embedded in action" (Argyris, et al. 1985). In this study, the entire video tape was used during the interview. In addition to documenting students' actions with materials, the video tapes captured non-verbal and verbal communication between the pair of students.

While Event I was designed to observe students' actions, the goal of the interview was to probe students' reasoning and intentions which led to their

actions. The interview checks inferences (made from observing the action setting) for possible confirmation or disconfirmation.

The interview was semi-structured whereby the researcher asked each dyad a set of questions to prompt conversation about individual experiments and overall sequences.

Procedures: Will you describe what you both are doing in this experiment?

Intentions: How does this experiment tell you which magnet is strongest?

Outcomes: What did this experiment tell you?

Sequence: You both did more than one experiment, why is that? Why did you change materials?

Conclusions: What made you both decide that this magnet is strongest?

Further probing by the researcher was dependent upon student responses or when actions in the video were not clear.

To prepare for the interview, the researcher previewed the video and, in most cases, transcribed the dyadic talk along with descriptions of their actions. A few specific questions, for each interview, were prepared (and asked when these actions appeared on the videotape) to clarify particular actions and meanings of students' comments. (see Appendix D for an example of a transcript).

Interviews with each dyad were conducted the day following the students' investigations. Each interview lasted about forty-five minutes. Both students of a dyad were interviewed together. Students watched the entire video of themselves experimenting on a video playback monitor. The researcher and students started, stopped and rewound the video as necessary. During the

interview, the screen of the monitor (video) and the interview (audio) were recorded by a video camera. The interview was also audio taped as a back-up.

Analysis of Data

The records of the study include video and audio tapes from all three events for each dyad. From these records the researcher conducted five levels of transformation for each videotape during the analysis.

Level 1. Descriptions of a dyad's actions and the verbatim talk between them (while they experimented) were transcribed for Events I, II and III by the researcher. Small diagrams were drawn on these transcripts as descriptors. Each transcript provides a storyline of a dyad's series of experiments (for Set 1 and Set 2 magnets), what they did and what they said to each other. Anecdotal notes were inserted as to when the videotape was stopped, rewound or forwarded. The transcripts from all events were typed on a computer.

Level 2. A matrix representing student experiments was constructed for each dyad from the transcripts of Event I and III. Each row of the matrix represents one experiment within the series. The six columns of the matrix contain the following:

Dyad# - identification of the dyad.

Action - a brief description of the dyad's actions with a small "snapshot."

Dyad Talk - relevant selections of dyad's talk to each other regarding he experiment (Event I).

Data/Method - researcher's notes about students' methods of gathering data (e.g. counting, measuring) and which magnets were used (Event I).

Espoused theory - dyad's reflections about the experiment from the interview (Event III).

Outcomes - researcher's notes about the dyad's conclusions, including their talk to each other and during the interview (Events I, III). These notes or comments include the outcomes of a single experiment (represented in a row) or general conclusions about which magnet is strongest. For instance, students made comments about which they thought was strongest (hunches) before stating a conclusion.

The purpose of the matrix was to create a working spread sheet of each dyad's series of experiments where the researcher could highlight items, draw arrows to link communalities across experiments (within columns), and carefully follow aspects of one experiment (within rows). The matrix offered a triangulation of data from three sources: observations of students' actions (Event I), their talk while they experimented (Event I), and the students' reflections of their actions (Event III).

Level 3. The researcher constructed models of magnetism from the matrices (Event I and III) and transcripts (Event I, II and III) from all dyads. The researcher's method of construction of these models is based upon work of Gentner and Stevens (1983). The authors describe such models as explicit ways researchers represent people's understandings of specific phenomena. They cite the following example.

> Patrick Hayes (1979) has analyzed the concepts involved in understanding the behaviour of liquids. This understanding enables people to predict when a liquid will flow, stand still, or spread into a thin sheet of a surface. Using Hayes' analysis, we can model the ways in

which people imagine liquids moving through time from one of these states to another.

In the previous example, analysis begins with the behaviour of liquids rather than a scientific explanation (i.e. principles of surface tension). These are behaviours that a person may observe. The authors also state, "The emphasis is on dynamic phenomena, so most of the devices or phenomena studied involve changes of state, often causally connected changes." The models presented in this study use concepts that involve the behaviour of magnets (magnets "pull" and "hold" objects) and permit inferences about students' understandings of the ways magnets interact with objects.

The models (representing students' knowledge) and the matrices (including student actions) were used by the researcher to construct a set of theories-in-use that infer the intentions and hypotheses that underlie dyads' experiments (Argyris, et al., 1985). In the study, theories-in-use state the observable effect of an experiment (from manipulation of the materials) that distinguishes the strongest magnet, for example, "The strongest magnet will pull a magnetic object from a further distance." In this case, a dyad uses the materials to observe 'how far' away each magnet can pull an object and compares distances across the three magnets.

Level 4. The researcher constructed Sequence Maps (see Figure 1). In Action Science, maps are used to model actions and typically entail diagrammatic or verbal representations of particular aspects of actions. In the present study, a Sequence Map is a two dimensional representation of a dyad's series of experiments and follow the sequences of theories-in-use, materials used, and outcomes across a series of experiments (Set 1 and 2 magnets). Across the top are columns that represent each experiment and lists the materials used. Along the

side, are nine rows, each representing one of the theories-in-use inferred from all dyads' experiments. Theories-in-use (with the exception of the last theory-in-use) are arranged according to the variable manipulated and whether or not they incorporate 'pulling' or 'holding' behaviours.

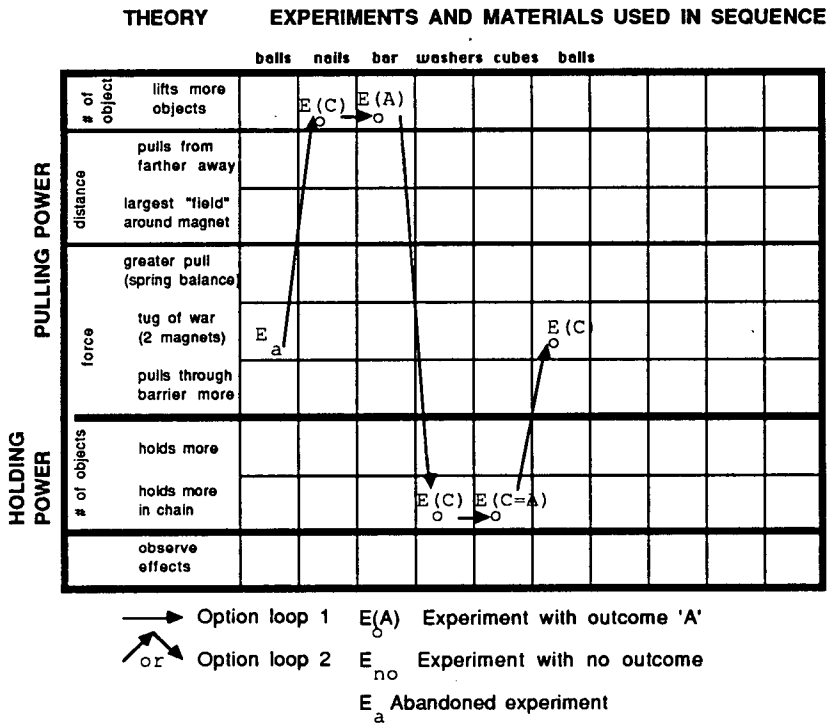


Figure 1. Example of a Sequence Map.

In the interior of the map, each experiment (column) is represented by one theory-in-use, indicated (in the appropriate row) by the following symbols: E_a (experiment was abandoned); E_{no} (experiment yielded no outcome); $E_o(A)$ (experiment with outcome). The outcome of the experiment, A, B, or C, is written next to the 'E_o' to indicate which magnet was determined as the strongest. Lined arrows connect the symbols.

The Sequence Maps show the following options dyads may use for consecutive experiments during the series. In a subsequent experiment, a dyad can:

1. keep the same theory and the same materials (repeat the experiment);
2. keep the same theory and change materials;
3. change the theory and keep the same materials;
4. change the theory and the materials; or
5. stop experimenting.

A horizontal line between symbols shows that a dyad used one theory for consecutive experiments, whereas a diagonal line shows that a dyad changed theories. Whether or not dyads changed materials with each experiment can be determined by reading the materials across the top columns. The maps also show: how many experiments were conducted (abandoned, with outcomes, without outcomes); the sequence of outcomes; variables manipulated; and whether the experiment involved 'pulling' or 'holding' behaviour.

Level 5. Five summary tables were constructed to show information across dyads, such as how often particular theories of action were used, the number of experiments conducted by each dyad and for all dyads. These tables were useful for the comparison of grade 4 and grade 7 dyads.

Limitations of the Methodology

While dyads are useful for reasons already mentioned, there are some limitations, particularly during the interviews. For example, in some instances an interview might be dominated by one student. The researcher attempted to ameliorate such a situation by using eye contact, friendly body language (such as hand movement while speaking), smiles and nods with the less assertive student. Another consideration is that during an interview, students were asked to reconstruct what they were thinking during the experimentation. There may be factors which affected these reconstructions such as students' beliefs that they have to defend their experiments rather than explain them, or students' inability

to explain what they did in an experiment. Also, their ideas may have changed as a result of the experiments and their reconstructions may reflect this change. However, from a research perspective, a difference between student reconstructions and what appears on the videotape (student actions) is useful information for the study.

CHAPTER 4

Results

Introduction

The results presented in this chapter are divided into three main sections, Planning, Acting, and Evaluating. Data are presented on how students designed, conducted experiments and made conclusions about their experiments. Aspects of planning and evaluating likely occur throughout action, however, they are separated in this chapter for the convenience of presenting the results. Results for students from both grades are presented together within these sections. Five tables and one figure provide results according to grade level for comparison purposes.

Planning. This section begins with student beliefs and knowledge of magnets and experimenting as a precursor to Problem Setting and Theories-in-use. Tables 2, 3 and 4 compare student language and Theories-in-use for grade 4 and grade 7 dyads.

Acting. This section includes ways students used materials, their modes of data collection within experiments, and student action sequences during their series of experiments. Table 5 and Figure 5 compare the number of experiments conducted and action sequences of grade 4 and 7 dyads. Also, a Sequence Model (Figure 4) is presented which shows two different action sequences students used during a series of experiments.

Evaluating. This section examines aspects of student monitoring within experiments that resulted in abandoned experiments, controlled variables, and

explicit outcomes. Students evaluated when and how to make a final conclusion from a series of experiments. Strategies students used when deciding between variable data are presented. Student evaluations of their designed experiments are also included. Table 6 shows the number of experiments abandoned, with or without outcomes, for grade 4 and grade 7 dyads.

Planning

The action component of the study was the context for student talk while they experimented, and student reflections while they participated in an interview. The analysis of these dialogues yielded many insights into students' knowledge and beliefs about magnets, powerful prerequisites for making inferences about student planning.

Students' Knowledge and Beliefs about Magnets

Although students from both grades did not know what was 'inside' a magnet, all knew that magnets attract some metal objects at close range, likely from previous experience of using magnets at school or home. For example, DAN7 commented, "I don't know anything about magnets... I know what their effect is, they make certain metal stick to them." During the interview, some students spoke in detail about what magnets do. According to WIL4,

> A magnet is something that uses, I don't know really, maybe some sort of.. do you think a magnet can create electricity sort of? And sometimes I don't know how to explain what a magnet is, it is like a power to create things to come towards it but it can't usually create itself to come towards it [the object]... You know like sometimes in cartoons they show the magnet goes shhh [hand moves forward like a rocket]. The magnet

cannot usually do that, everything always comes to them. It can't be this far away [he runs to the back of the room].

DAN7 used the metaphor of a black hole to describe what a magnet does.

A black hole is almost the same as a magnet, whatever is close to it gets drawn in. Let's say a magnet is a black hole and iron filings are bits of space garbage; once it gets close enough it will get drawn in and then it will stay there and after a while it will weaken because the power is distributed through it; the same with black holes, when there's enough stuff it stops and creates a new star with it.

Throughout student dialogues, a variety of terms were used to represent what causes magnets to attract and hold objects. Table 2 provides examples of this language. Common terms were "power" and "force." In addition, Table 2 also includes student language representing magnet behaviours. All students disclosed two magnet behaviours (magnets pull and hold objects) with the following words: "pick up", "move", "pull", "lift"; and "hold", "carry", "stick to." Two grade 7 students stated that in their experiments (where magnets pulled objects and held objects) they used "the power of the magnet in different ways... The experiments were different, he was trying to see how much one [magnet] would hold whereas I was seeing how much one would pull." Students distinguished pulling behaviour by the movement of an object towards the magnet (pull, lift, pick-up). Holding meant the object adheres to the magnet after being pulled to the magnet or after students put objects directly on the magnet (hold, stick, carry).

Students knew little about magnetic poles. TOM4 recalled the negative and positive "sides" of magnets and said if the negative sides are put together, the magnets "might try and get away from each other." JEF7 remarked that the positive side is usually stronger than the negative. During student experiments, however, four dyads noticed that some sides (the poles) of the magnets "worked" (pick up, hold) better than others. JAN4 offered an explanation. "I think I might know, I think inside [the magnet] there may be something to keep it all in and it's thicker on the sides or something ..."

Table 2

Words used by dyads to describe magnets and how they affect magnetic objects

Dyad	Grade	Words describing magnets	Words describing how magnets affect magnetic objects	
			'Holding' words	'Pulling' words
KEV, WIL	4	charge, power, electricity	hold	pick up, lift, pull, suck, move
AMY, JAN	4	magnetic force	hold, stick	pull, suck
JIM, TOM	4	sucking power, power	hold, stick	pick up, suck, move
LEA, MEG	4	magnetic, magnetism	stick to	pick up, lift, move
ROS, KAY	7	suction, magnetic pull, power, stream of pull	stick to, carry	pick up, lift, carry
DAN, JEF	7	unseen force, rays, power, energy	stick, carry, hold	pick up, lift
SUE, ANN	7	energy, force	stick to, hold	pick up, grab, pull
JON, ALI	7	magnetism, magnetic force, magnetic rays	carry, hold	pick up, move, lift

This section presented student knowledge about how magnets behave. The following section discuses how students explain the interactions between a magnet and objects (as they explain what they observed).

Student Models of Magnetism

The following models represent ways in which students understand how magnets interact with objects (see Figure 2).

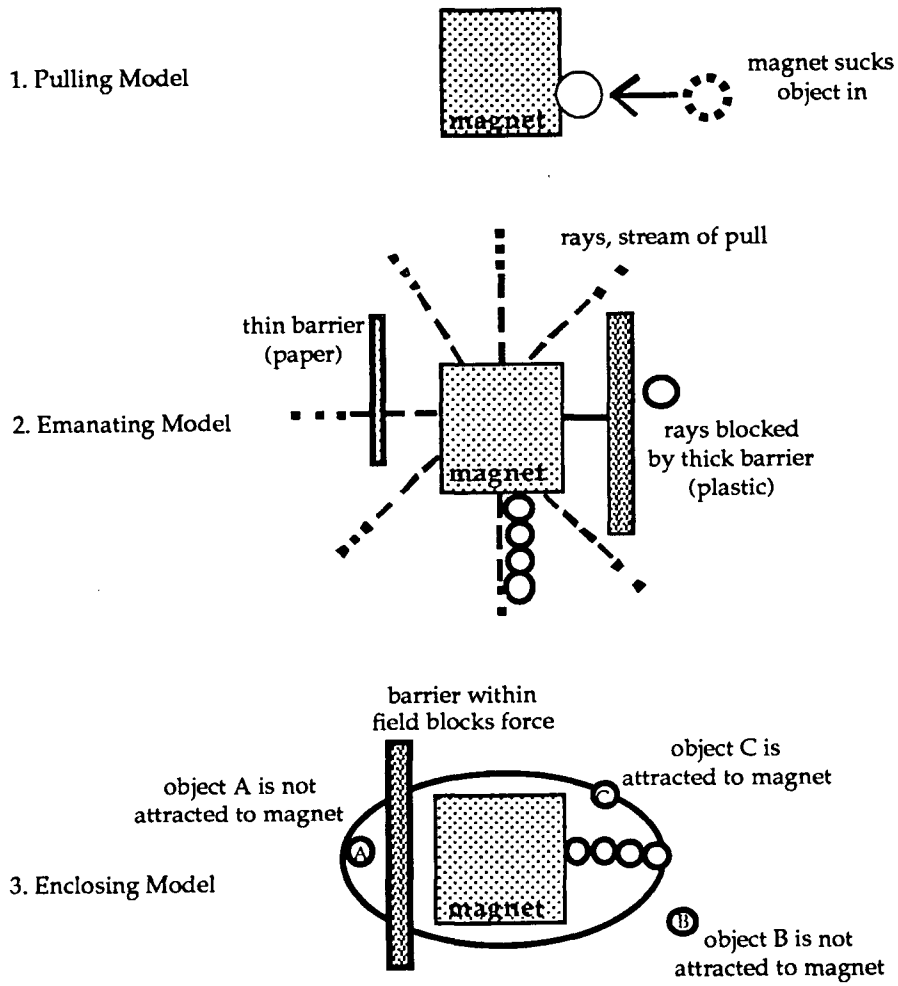


Figure 2. Student Models of Magnetism.

1. Pulling Model. Students simply related what they observed, a magnet pulls an object from close range. Three grade 4 dyads described magnets sucking objects, "the magnet has to suck in." In this model, pulling or sucking are behaviours of magnets that affect nearby metal objects causing them to move to the magnet. KAY7, used the following metaphor, "OK, let's say you've got a cup of water and you have suction up here, like those suction straws that they have at the dentist, and it's up here and it sucks the water up."

2. Emanating Model. - In this model, the magnet emits some subtle substance (i.e. "rays", "energy") that affects certain metals. This substance "goes through" metal objects held in a chain or is "blocked" by some non-magnetic objects (referred to as "barriers") such as thick plastic or wood. ALI7 described the rays that come from a magnet as "things with power like invisible stuff, like sun rays." KAY7 stated that barriers can partially block the "stream" which comes from the magnet. "It's like a hose, if you put your finger on part of it, it blocks up the main water stream but some water escapes." According to one student, emanations become stronger when a magnetic object is near the magnet.

3. Enclosing Model. - This model shares two characteristics of Model 2: the presence of something between the magnet and magnetic object (i.e. "force"); the force can be blocked by non-magnetic materials. However the force closely surrounds the magnet. DAN7 (the only student to use this model) gave the following description.

> I think the magnet is enclosing the force, so it doesn't really go out...It's always there but you can't see it until something is there and it has a reaction to it... So, you could say that it is this far around [makes a small circle around the magnet with his finger] and once it [object] gets to about here [near magnet] it's on the barrier and gets pulled in.

DAN7 recounted "waves" of a magnet he saw in a book and added that the force comes out "bigger" at the ends of the magnet. A piece of non-magnetic material within the circle can "block" the force.

Students (other than DAN7) used Model 2 exclusively when talking about experiments that used non-magnetic materials (barriers) between magnets and magnetic objects, and when magnets held magnetic objects in a chain (magnetic induction). Otherwise, students used Model 1 and spoke of magnets pulling objects (i.e. from a certain distance). That is, in specific instances, students talked about the pulling behaviour of a magnet (model 1) and emanations that "come out of the magnet" (model 2).

Students' Beliefs and Knowledge about Experimenting

At times during the interviews, students discussed experimenting. For all students, an experiment meant either "to find" or "try something out." However, two grade 7 students added that an experiment "proves something." DAN7 related experiments to "proving" theories in science.

> Usually in an experiment you prove yourself right and other people wrong because... isn't that right, that in science if one of them [a scientist] has a theory, the other ones try and prove the theory wrong because that's the way they are supposed to decide when something is right- everybody has done it and still haven't proved it wrong? Then people will begin to think he [the scientist] is right and then more people will try to prove him wrong.

All dyads conducted a series of experiments before reaching a conclusion. KEV4 provided a reason, "So it would be more equal; it would be hard to figure out from only one or two experiments." Two students believed that a person (including themselves) could not be one hundred percent sure of a conclusion from one or many experiments, "because there is always a chance that it won't [be right] because an experiment is just to see what, so you can't be 100% sure" (JAN4). KAY7 and ROS7 claimed to be 100% sure of the results of their experiments for a magnet set.

Three students stressed the importance of having an idea before starting an experiment. For instance, according to JON7, an experiment is "when you have an idea and you see if it works." Since dyads conducted a number of experiments for each magnet set, ideas emerged during each series. JAN4 and AMY7 used an analogy to explain how their ideas emerged during a series of experiments.

> AMY7: You pretty well need an idea to start off with. You've been doing one thing and you decide to change and do this and both things go together.
>
> JAN4: It's like if you are talking about one thing, like maybe you are talking about school and then you end up talking about Disneyland...When you're talking about school and one of your friends is going to California and then, 'Oh, we went to California once' and 'that's where Disneyland is'... and then there is Disneyland and you start talking about it.

Students also mentioned having a prior idea or "hunch" about what will happen in an experiment. JEF7 said he had hunches about his experiments like

scientists have, "You get a hunch, Albert Einstein would get a hunch." However, JON7 explained that his hunches did not always "work." "We thought some of them [the experiments] would work differently than they did."

In this thesis, student knowledge of experimenting, like their knowledge and beliefs about magnets is viewed as an important component of student planning.

Problem Setting

The students were asked to determine which magnet is strongest using the materials in front of them. This operational question focussed students' attention on the behaviours of magnets and on strength as a property of magnets. According to JEF7, "Strongest means more holding power or more pulling power." The materials provided a means to "show" which magnet is strongest. For example, KAY7 explained, "It's just a plan of how to work it. If you think about magnets, what do magnets do and how can we show what magnets do, how can we show which magnet is strongest." Also, the materials may have provided cues for "how to" show which magnet is strongest, evoking particular actions. For example, non-magnetic materials were used in the same way by all students. Whereas, other materials were used in different ways by dyads.

The operational question prompted students to compare the magnets. The students manipulated the following three variables, distance, number of objects, and force to measure quantitatively magnetic strength for each magnet.

Distance - students varied the distance between the magnet and object to determine the maximum distance (how far) a magnet could pull an object.

Number of objects - students varied the amount of objects to determine the maximum number of objects (how many) a magnet could hold (on the magnet or in a chain) or pull (with or without a barrier between).

Force - students pulled magnets apart (with objects between them), or pulled the spring balance and the magnet (adhering to a washer hooked onto the spring) apart. In the former case, when the magnets were pulled apart, students counted how many objects remained on each magnet. In the latter case, force stretches the spring which pulls the washer from the magnet. The student who used this experiment read the scale on the spring balance (how much force) when the washer was pulled from the magnet.

Theories-in-use

The following theories-in-use are inferred student hypotheses (theories of control) that guide what students manipulate, and how they determine the strongest magnet from the observed effect (from what is manipulated). Across all dyads' actions, nine theories-in-use were identified. In the first eight theories-in-use, distance, number of objects and force are manipulated. The ninth theory-in-use represents student explorations with the magnets and materials.

1. The strongest magnet will pull a magnetic object from the greatest distance. Typically, students held the magnet at some distance either above or on the table near the object, and moved the magnet towards the object. When it became attracted to the magnet, students noted the distance between the magnet and the object and either measured or estimated that distance. Several times students used the compass as the object and watched for the first movement of the needle as the magnet came closer. Students judged the strength of a magnet according to how far away it could attract the object. The greatest distance indicated the strongest magnet.

2. The strongest magnet has the largest magnetic field (power which surrounds the magnet). One student attempted to show the magnetic field using filings on top of the plastic square with a magnet underneath to show how far the magnetic field extended.

3. The strongest magnet will pull, move or lift the greatest number of magnetic objects. When the magnet pulls or lifts objects to move towards it. Typically, students held the magnet over a pile of similar objects and counted how many were lifted. The greatest number determined the strongest magnet.

4. The strongest magnet will pull more objects through a (non-magnetic) barrier. Students placed a non-magnetic object (plastic, wood, plasticine or paper) between the magnet and a magnetic object. They did not manipulate the number or types of barriers. They attempted to find how many magnetic objects a magnet could attract or move with a barrier in place. When a magnet could not pick up or move an object, students explained that the barrier "blocked" the magnetic "rays."

5. The strongest magnet will hold more magnetic objects. Students put objects on the magnet and counted how many adhered to the magnet. The strongest magnet "held" the greater number of objects. At times when students used a large number of objects (paper clips, nails), the number of objects which did not remain on the magnet was counted and the smaller number determined the stronger magnet.

6. The strongest magnet will hold more magnetic objects in a chain. Students stacked objects such as washers or cubes, touched the magnet to the top of the pile and lifted, whereby the objects formed a chain below the object touching the magnet. Students determined the strength of the magnet by how many objects were in the chain.

7. The strongest magnet will pull magnetic objects from a weaker magnet (called "magnetic wrestling" or "tug of war"). Students either put one object or many objects on one magnet, touched a second magnet to the object/s and pulled the two magnets apart. Students explained that the stronger magnet was left with the most objects or the single object. When iron filings were used as objects, students estimated 'how much' filings remained on a magnet.

8. The strongest magnet has the greatest measurable pull. One student measured (how much) "magnetic pull" using the spring balance. DAN7 attached a washer to the hook of the spring balance, and lowered the spring balance to the magnet. He pulled the spring balance and held down the magnet on the table until the washer was pulled from the magnet. The number corresponding on the scale of the spring balance was recorded. The largest number was determined the strongest magnet.

9. A magnet causes an effect with certain types of materials. Students explored the effects of magnetism with objects or with the other magnets. For instance, students attempted to find out where the needle of the compass pointed when a magnet was near. Generally, the purpose of such exploration was to gather information and often prompted an experiment that determined strength (i.e using the distance variable).

Table 3 shows the theories-in-use each dyad used across both magnet sets. All dyads used at least three theories-in-use. One grade 7 dyad used only one theory in four experiments with Set 1 magnets (they used two other theories in Set 2). Two theories (the strongest magnet has the largest magnetic field; the strongest magnet has the greatest measurable pull) were used exclusively by one grade 7 student. Table 4 shows dyads' espoused theories from two events, Event I (talk while they experimented) and Event III (students' reflections during the interviews) for three theories-in-use for a grade 4 and grade 7 dyad.

Table 3

Theories in Use used by individual dyads

Theory	Grade 4 Dyads				Grade 7 Dyads			
	KEV WIL*	AMY JAN	JIM TOM	LEA MEG	ROS KAY	DAN JEF*	SUE ANN	JON ALI*
The strongest magnet will pull a magnetic object from the greatest distance	X	X		X	X		X	X
The strongest magnet has the largest magnetic field						X		
The strongest magnet will pull, move or lift the greatest number of magnetic objects	X		X	X	X	X	X	X
The strongest magnet will pull more objects through a (non-magnetic) barrier	X		X	X		X	X	X
The strongest magnet will hold the greatest number of magnetic objects		X	X			X	X	
The strongest magnet will hold more magnetic objects in a chain	X		X			X	X	X
The strongest magnet will pull magnetic objects from a weaker magnet	X	X	X				X	X
The strongest magnet has the greatest measurable pull						X		
A magnet causes an effect with certain types of materials	X		X	X		X	X	X

*Students in dyad worked individually at times

The espoused theories in Event III include students' reflections' of their intentions (descriptions of what they did) and purpose (how the experiment determined the strongest magnet). The table shows similarities of the intentions and purpose of students' experiments between the two grade levels. In the

Table 4

Examples of dyad talk from a grade 4 dyad and a grade 7 dyad for 3 experiments

Theory	Grade	Talk While Experimenting	Talk During Interview	
			Intention	Conclusion Criterion
The strongest magnet will pull a magnetic object from the greatest distance.	4	I've got an idea ... because this one [magnet] is the **furthest back** to pull the ball bearing along the ruler.	There was a ball bearing and we were seeing **how far** away it [magnet] it would pull the ball bearing towards it.	The **furthest away** is the strongest. The ruler is measuring the distance.
	7	We can see **how far** this [magnet] is off the ground until this [washer] comes to meet it with each magnet.	We were putting 3 metal pieces and then getting each magnet and seeing **how far** it was above the graound before it [magnet] attracted and brought the piece of metal up.	The one that was **highest up** while it attracted was the strongest because it has the strongest pull towards the washer to bring it up from further up.
The strongest magnet will hold the greatest number of magnetic objects.	4	Let's see if this can hold **how many** nails; see how many. I'll just load this with as much as it can and we'll see **how much** it can do with this bar.	The **more stuff** you put on there [magnet], the more it could hold, if could only hold one nail and it falls off you know it wasn't very strong.	We added on a whole bunch of stuff until it wouldn't take anything else and then we compared them. This one was the strongest because it could **hold all this** stuff and the others couldn't.
	7	Let's attach as many things as we can to it [magnet]. If we can attach lots ot stuff and see **how much** it can hold and try it on the other ones to see if they [magnets] hold as much.	It was **how much** it would hold. When you put them on the magnets, you are actually holding them and they can't come off.	"C" did **half the stuff** as the others.
The strongest magnet will pull, move or lift the greatest number of magnetic objects.	4	See who [which magnet] can pick the most nails up, see which can pick up **the most**.	We pile them [nails] so it [magnet] can get **more**. If you spread them out it covers more area and can't touch the magnet.	The strongest is the one that takes up **the most**.
	7	Get the nails. Let's see **how many** it can pick up.	We were piling all the nails together and seeing **how many** nails each one [magnet] could pick up.	One magnet wouldn't pick them up; one would, so it was the strongest.

examples, dyads from both grade levels state clearly their intentions and what criterion (how many, how much and how far) determines strength.

Figure 3 is a diagrammatic representation of the students' knowledge elicited in the study. Students' operational knowledge involves how magnets behave based on what can be observed; magnets pull and hold some metal objects. Eight specific theories-in-use distinguish how students compared the "holding and pulling power" of the magnets in order to find the strongest magnet. The three student models of magnetism, represented in the figure by circles show the theories-in-use they explain. For example, most students used a different model to explain how a magnet pulls objects through a barrier and how magnets pull an object without a barrier. Models of magnetism are based upon student explanations and reconstructions of their experiments and represent ways students understand the interaction between the magnet and magnetic object.

First Impressions about the Sizes and Weights of the Magnets

None of the dyads decided which magnet was strongest based only upon its size or weight. All but one grade 7 dyad concluded that the smallest (not lightest) magnet was strongest in Set 2. During the interviews, however, many students spoke about the size and weight of the magnets in relation to strength. According to KAY7, "A was the biggest and strongest [Set 1] so, I thought the biggest would be the strongest the next time [Set 2] but it wasn't." As students experimented, they talked to each other about the different sizes of the magnets. KEV4 commented to his partner when he first started working, "This one is quite big, so it might be pretty powerful." Later during the interview he stated, "Sometimes they're [the strongest magnet] bigger, sometimes they're smaller, it depends what kind of middle they have."

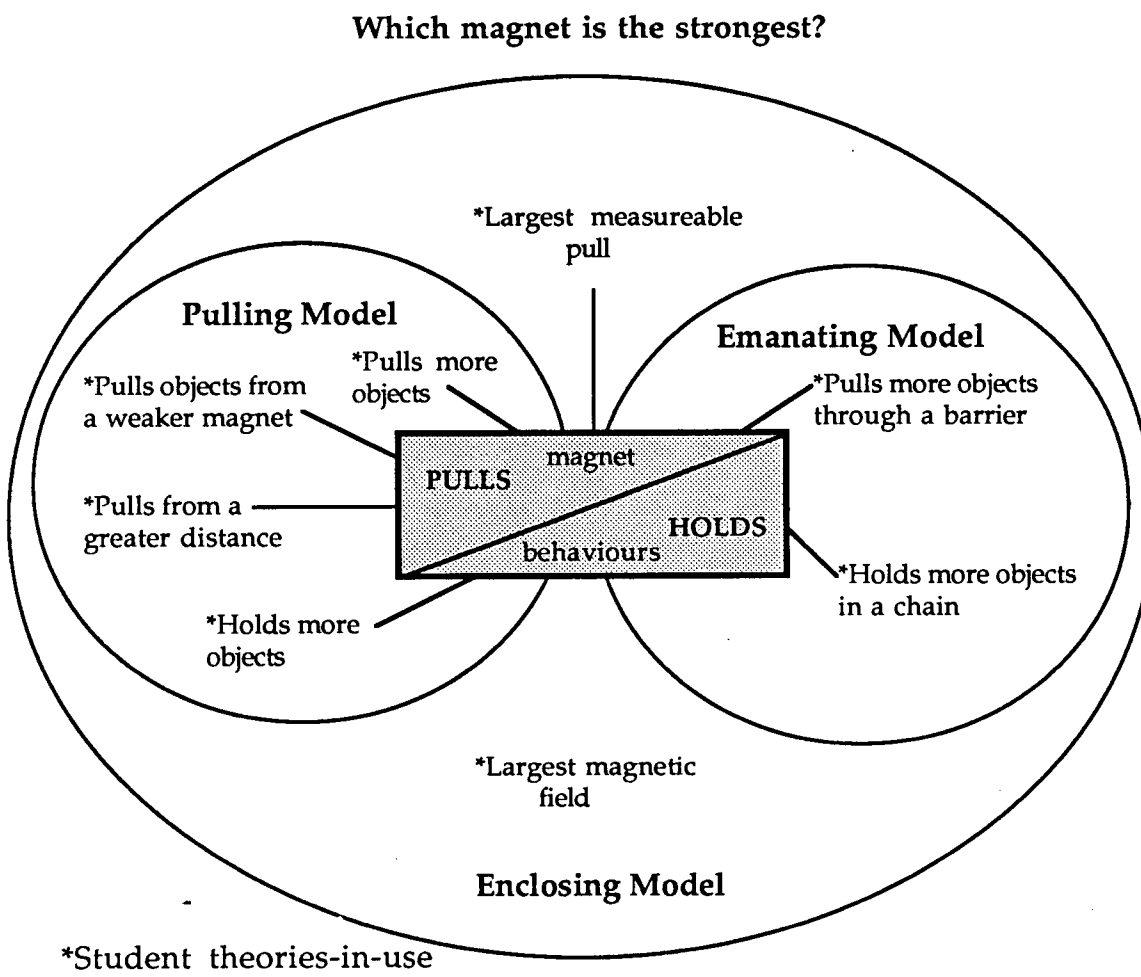


Figure 3. Relationship between operational knowledge, theories-in-use and models

During the interview, DAN7 and JEF7 talked about size as a first impression.

DAN7: That's another thing, like you have a very small amount of nuclear explosives that may cause more damage than much more dynamite.

JEF7: ...your first impression is that 'A' [in set 2] is going to be much stronger than 'C' but after I did a test it was the exact opposite.

DAN7: Sometimes little kids when they hit me think I don't get hurt, they think that since I'm bigger that I'm stronger as well...

Interviewer: So how important are first impressions when you do work like this?

DAN7: They are important because you have something to compare it to. If you look at it [magnet] and you think it is going to be strong and it fools you, you think about it, and say, hey maybe they are bigger but not stronger.

AMY7 and JAN4 presented a different but equally thoughtful argument regarding the size of a magnet and how many objects it can hold. They argued that size may make a difference in determining the strongest magnet since the larger magnet has more "room" (surface area) to attach objects, therefore "holding" more of them.

The weight of the magnets influenced students more than size. For example, in Set 2, the 'B' magnet was large and light, and several dyads thought it was not a magnet. "It doesn't feel like a magnet [KAY7]." Students talked to each other, while experimenting, about the weights of the magnets. JIM4 commented to his partner TOM4, "See which one is heavier, don't use the light one [B]." During the interviews, ROS7 stated that the strongest magnet was always heaviest. However, none of the students weighed the magnets with the spring balance provided but used their hands to "feel" the weight of a magnet.

First impressions were therefore important but not conclusive for the students.

Acting

In this section, students' actions include their manipulation of materials within individual experiments and the sequence of actions across their series of experiments. For individual experiments, students' use of materials and modes of data collection were examined. For the series of dyads' experiments, changes of theories-in-use and materials for consecutive experiments were examined. Therefore, the researcher could map the sequence of dyads' actions from when they begin experimenting until they state a conclusion for each magnet set

Students' Use of Materials and Magnets

In student experiments, materials were used singly or in combination (e.g. washer and ruler). During a series of experiments, dyads manipulated similar objects in different ways that represented more than one theory-in-use (category 1), and different objects in a similar way that represented one theory-in-use (category 2). For example, in category 2, all dyads who used non-magnetic materials used them consistently as a barrier or obstacle between the magnet and magnetic object (see Figure 4 for other examples).

In a few instances, students used the magnets without materials to estimate their weight (using their hands) or to explore ways magnets behave together. Students used magnets with materials either singly, side by side (two magnets at once but with separate objects) or with two or more magnets together in a competition (magnets with one set of objects). When magnets were used singly, data were collected for each magnet (e.g. how many paper clips it could hold) and compared. Generally, magnets were used side by side when dyads compared distances by estimation rather than measurement. For example, a student held a magnet in each hand and lowered the magnets towards objects on the table. After each object was attracted, the student held the magnets still,

magnets still, observed and compared the distances between magnets and objects and estimated the greatest distance. In a competition, two or three magnets were used and one judged strongest from a single event. For instance, a student placed several steel balls between two magnets and pulled the magnets apart. The magnet left with more balls was deemed stronger.

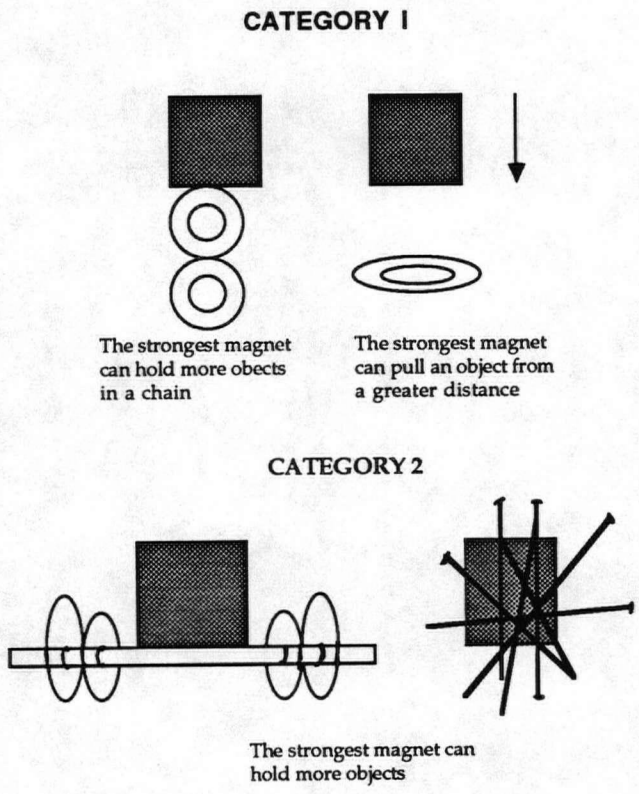


Figure 4. Students' use of materials

Non-magnetic Materials Used as Barriers

Three dyads from each grade used non-magnetic materials as barriers. Typically students placed paper, plasticine or plastic sheets between a magnet and magnetic object. None of the students mentioned these objects created a distance between the magnet and magnetic object. They stated that non-magnetic

materials affect the magnetic field by "slowing it down" or causing a "resistance." When students noticed they could not "feel a pull" beyond some non-magnetic barriers, they concluded that these materials were "thick", "insulators","heavy", "hard weight," "dense, full of things", "compressed" and they "block magnetic rays", "stop the energy from getting through", or "put a barrier for the magnetic force."

Five dyads (three grade 7 and two grade 4) used magnets to lift "chains" of washers or paper clips where one object hangs from an object that touches the magnet. These objects were not viewed as barriers. Rather, students stated the magnetic force "travels" from one object to the next. JAN4 made this distinction, "It [magnetic force] can only go through metal and not anything else."

For Event II, dyads were presented a piece of wood and a piece of plastic (with holes), two metal sheets (that are attracted to the magnet but do not become magnetized), and a small steel cube. The researcher asked dyads if they could show which magnet was strongest using these objects and Set 2 magnets (since they were familiar with these magnets from Event I). Students statements about these materials provided insights into their understandings of magnets.

According to the following students the magnetic force goes through the holes in the plastic.

JEF7: The plastic would slow it [magnetic force] down. Where there are holes, it won't slow down as much.

ALI7: The rays can go through the holes.

KEV4: The plastic is thick and there are a few holes to let the power through.

Some students believed the wood blocked the magnetic power because it had many layers, or was compressed and hard. ALI7 mentioned that wood has tiny holes. However, when he did not feel a pull beyond the wood, he stated, "because the holes are small, there isn't room for the magnetism to go through the holes."

Two grade 4 students made interesting conclusions regarding the metal sheets. These students found that the metal sheet, between the magnet and the steel cube, did not pull the cube (the cube did not adhere to the sheet). They expressed surprise but attempted an explanation. KEV4 said the surface of the sheet was probably coated.

> I know it is different on each side [of the metal sheet]. When I tried to pick up [the cube] the magnet had more resistance to pick it up, I think there was a coating of some other kind of metal or something... maybe copper or something non-magnetic.

JAN4 explained that the magnetic force could not go around the large metal sheet.

> Usually it [magnet] will pull through nails and you hang the nail down and then you put another on [forming a chain]...[it doesn't work with the metal sheet] because it [magnetic force] can't really go around this sheet and with the nails it can go all the way around and if this was just a small sheet, it probably could.

Data Collection

The provided materials appeared to have influenced ways dyads collected data. For instance, dyads counted how many steel balls, paper clips or washers to determine. In some cases, a particular theory-in-use prescribed a mode of data collection. For instance, finding which magnet can pull an object from a greater distance required measuring or estimating the distance between the magnet and object (from the point where it is attracted).

Dyads used the following four modes of data collection. They represent means of gathering data as students determine 'how many', and 'how far.'

1. Estimating- students estimated distances between objects and magnets and the amounts of large numbers of objects, especially filings. Dyads also estimated the weight and size of magnets. Seven of the eight dyads (all but one grade 7 dyad) used estimation some time during their series of experiments.

2. Counting- students counted the number of objects a magnet could hold (on the magnet or in a chain), lift, pull through a barrier or from another magnet. Five of the eight dyads used this mode (three grade 7 dyads, two grade 4 dyads).

3. Computation- Two dyads subtracted (mentally, rather than on paper) the number of objects not picked up by a magnet (from counting) from the total number of objects (counted and put in a pile). All dyads compared numbers (which number is larger) of objects counted or distances measured to make conclusions.

4. Linear Measurement- Half the dyads used a ruler to measure distances between magnets and object (three grade 7 dyads and one grade 4 dyad). JIM4 and TOM4 attempted to find the area of a quantity of filings and measured the dimensions of each pile of filings moved by two magnets. One pile measured

1cm x 3cm and the other 2cm x 2cm. However, he did not decide which area was larger.

Three dyads kept written records of their data (two grade 7 and one grade 4). However, only DAN7 and JEF7 referred back to their records while making the final conclusion. DAN7 stated why they kept records.

> Because I don't have to go back to my memory, I write it down and it made it easier...Yea, because you can refer back to it, like in Murder She Wrote [a TV series], she writes it down and she refers back to it and it leads up to a certain solution to that case...It's [data] there and you've done it and you are sure that it's there, you look back.

Sequence of Actions

All dyads conducted a series of experiments (some of which were not completed) with each magnet set before finally concluding which magnet was strongest. For the analysis of this study, the beginning of a new experiment was determined by a change of materials or theory-in-use. Dyads' talk to each corroborated when an experiment was finished or abandoned. For instance a student might say, "Let's try something else" at the completion of an experiment, before an experiment outcome is reached or before all three magnets are used. (An outcome is a result for an individual experiment and a conclusion is the final decision for the strongest magnet in the set.)

For both grade levels, dyads carried out and abandoned more experiments with Set 1 magnets than with Set 2 magnets. Also, most dyads repeated experiments used with Set 1 for Set 2 magnets. Grade 7 dyads conducted a total of forty experiments for Set 1 magnets and twenty-five for Set 2 magnets. Grade 4 dyads conducted forty-one experiments for Set 1 magnets and sixteen for Set 2

magnets. Table 5 shows the frequency of experiments in each magnet set for each dyad. Students in three dyads performed some experiments independently rather than together, therefore their total number of experiments conducted per magnet set is higher. These dyads shared results of their experiments and agreed on a final conclusion.

Table 5

Number of experiments for individual dyads in each magnet set

	Dyad	Number of Experiments	
		Set 1	Set 2
	KEV, WIL	23*	4*
	AMY, JAN	2	2
	JIM, TOM	10	6
	LEA, MEG	6	4
Grade 4 Total		41	16
	ROS, KAY	4	5
	DAN, FEF	10*	6*
	SUE, ANN	13	6
	JON, ALI	13*	8*
Grade 7 Total		40	25

*Students worked individually on some experiments

For each dyad's series of experiments (for each magnet set), change or repetition of theories-in-use in successive experiments was noted. Figure 5 is a Sequence Model that shows two different sequences (called Option loops) that dyads implemented during a series of experiments. As the model shows, initially, students were presented with the operational question and materials. The initial stages represent components of tacit and explicit planning in response to the operational question and the materials: problem setting (selecting knowledge schemes, framing the context), selecting a theory of control (a hypothesis and interpretive frame) and deciding which materials to use (to show

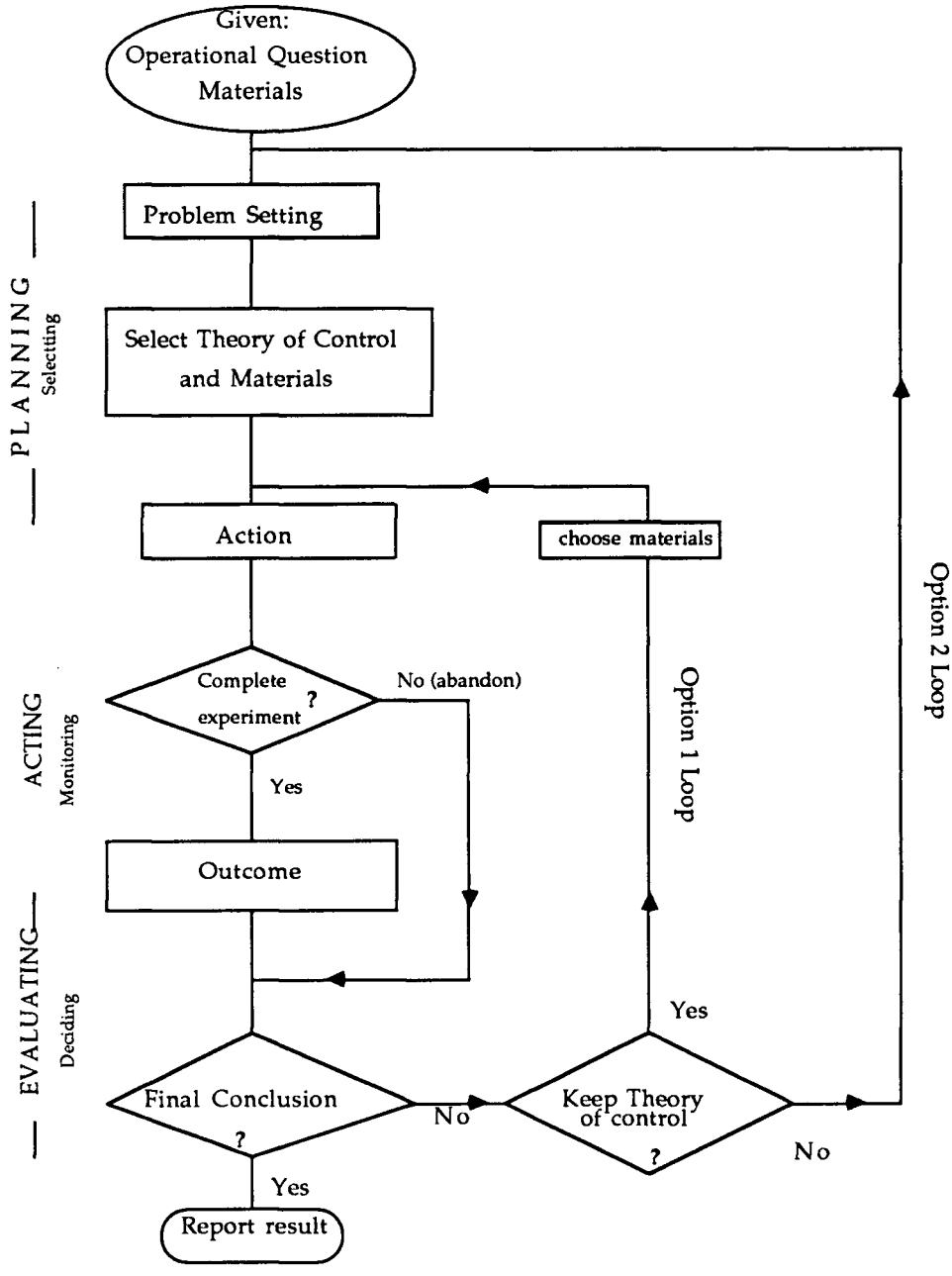


Figure 5. Sequence Model.

which magnet is strongest). The theory of control is what the students referred to during interviews as "an idea" (JON7: "When you have an idea and you see if it works.").

The Action rectangle of the model represents the observable interactions with materials by the students during one experiment. The talk between the dyad is considered a form of action. Such talk may include suggestions of what to try, instructions to each other, and the data of an experiment. Students manipulated materials and monitored the consequences. At times, dyads abandoned experiments before all three magnets were used and started a new experiment (see "Abandoned Experiments" in the following section). In the Sequence Model, a dyad may either repeat or abandon an experiment (i.e. no outcome). Dyads then decide whether or not to conduct a new experiment.

In the model, outcomes refers to the results of the experiment. For example, students observe the effect of their experiment (e.g. the magnet attracts the washer from 9cm away) and evaluate whether or not their intended consequences (of the experiment) are achieved. Few dyads recorded such outcomes, most relied on their memory during the series.

The students were the sole arbitrators of when a task was completed and when they had reached a final conclusion. If a final conclusion was not reached after the first experiment, students used two options for subsequent experiments:

1. Option 1 Loop - Keep the same theory-in-use. Dyads frequently conducted a similar experiment as the previous one but used all or some different materials. This loop, represents a new experiment within the original (or previous) frame and theory of control. Dyads then repeated the procedures with different materials and interpreted the consequences of the new experiment (e.g. how many balls are held) in a similar way to the previous experiment (e.g. how many washers are held). All dyads used this option at some stage during the task. Only one grade 7 dyad used it exclusively in one magnet set.

2. Option 2 Loop - Change the theory-in-use. In this option, dyads implemented a new theory of control and changed materials for a successive

experiment. This option was common for all dyads and was used almost twice as often as Option 1 loop. In the Option 2 Loop, the task is reframed in the sense that a new theory of control is implemented. In many cases, a different variable is manipulated also (i.e. number of objects, distance, force). Therefore, the way the new experiment is interpreted is different than the previous one. Typically, the variability of dyads' data led them to longer sequences of experiments where this option was frequently used. In the figure, this loop goes back to Problem Setting since students chose another theory of control. Like Option 1 Loop, all dyads used this option during a series of experiments.

During a series of experiments, dyads may pass through both options, sometimes repeating an experiment with new materials, or changing the subsequent experiment completely (see Chapter 5 for discussion). They may pass through either or both loops several times before coming to a final conclusion and completing the task. Dyads did not opt to keep materials and theory of control (repeat an experiment), or keep materials and change theory of control in consecutive experiments. That is, dyads changed materials with every new experiment but frequently used the same theory of control.

Dyads chose new materials or added to those previously used with every experiment. Students stated the following reasons for such change.

1. The materials used previously "didn't work." For example, KAY7 and ROS7 changed materials when they discovered that the steel balls rolled to one side of the magnet (the pole).

2. Students changed materials in the subsequent experiment when a more discriminating unit was desired. For instance, students switched from the large steel balls to the small ones when two magnets could lift the same number of large balls. According to JIM4, "When you get littler [small balls] you get more exact."

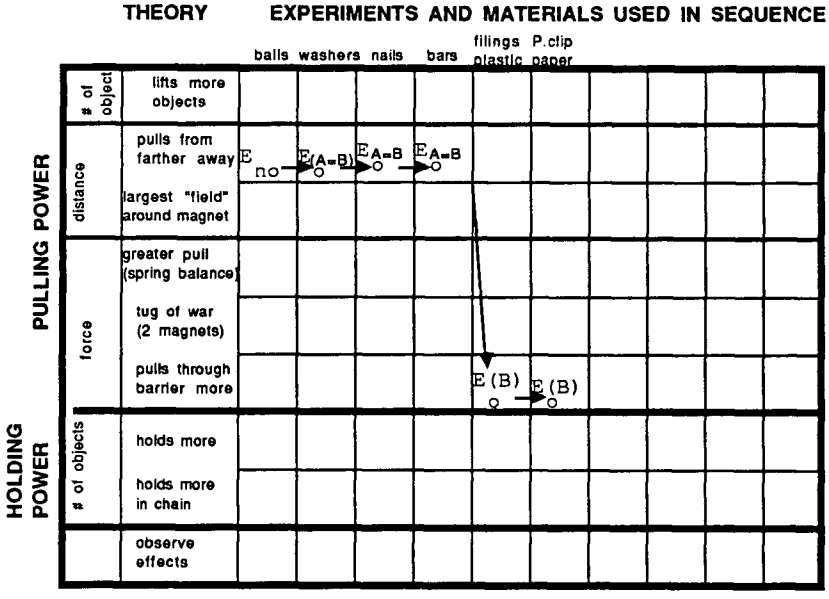
3. Students stated they changed materials because different materials may yield different results (one magnet may pick up more washers and another magnet in the same set picks up more paper clips). Students were uncertain as to why some "metal" objects are not attracted to magnets which may have led to such a conclusion (see Chapter 5 for discussion).

Figures 6 and 7 show sequence maps from four dyads. A sequence map shows materials used for subsequent experiments along the top and theories-in-use (in a specific order) along the side. Each column represents one experiment and shows which theory-in-use was implemented and if the experiment was completed with an outcome, completed without an outcome, or abandoned. Dyads from both grades show two similar patterns of options. The first two examples of the figure show a pattern where dyads (from each grade) used Option 1 Loop for a sequence of experiments (in one magnet set). The second examples show a zig-zag pattern where two dyads used Option Loop 2 most frequently and changed manipulated variables. Sequence maps show that each dyad used both options sometime in one or both magnet sets. All dyads shown in Figure 6, used one of the options predominantly.

Evaluating

The data from the study indicate that students monitored and evaluated consequences while experimenting. For example, dyads frequently decided that an experiment was not "working" and abandoned it before all three magnets were used. They also evaluated the appropriateness of the materials and made decisions about controls (e.g. use the same size washers). At the end of an experiment, students talked to each other about the outcome and made decisions as to whether or not they needed to do another experiment. This section

Grade 4



Grade 7

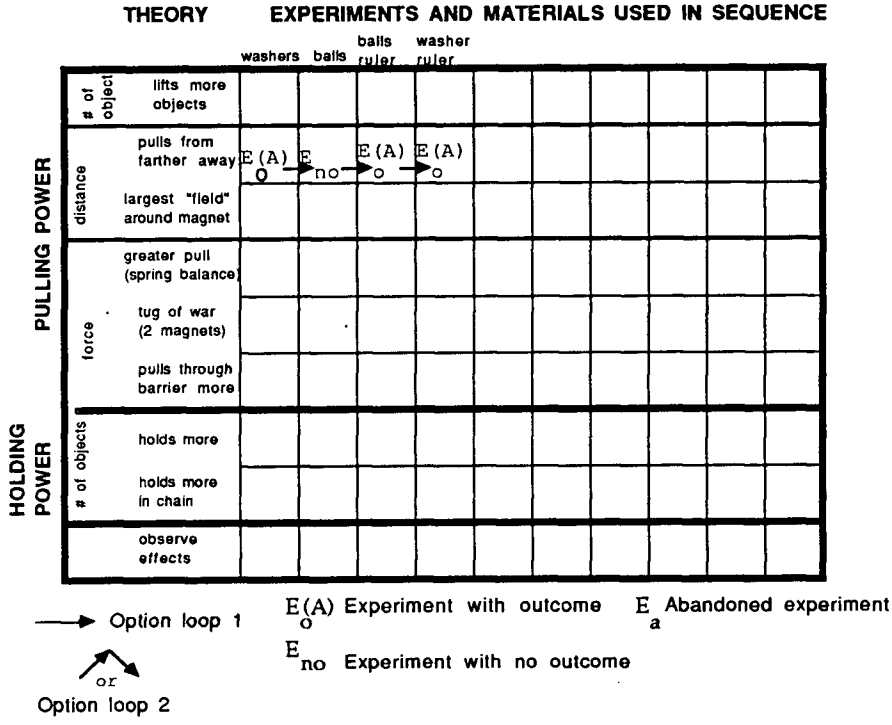
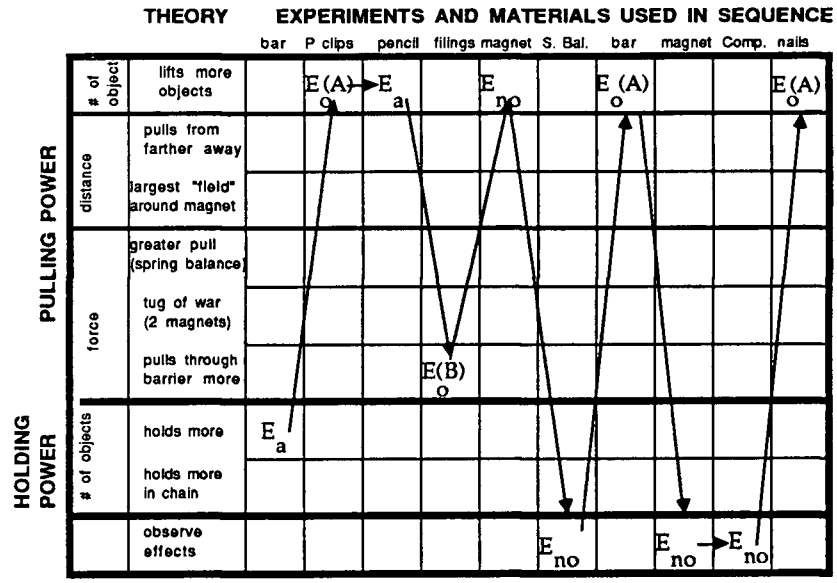
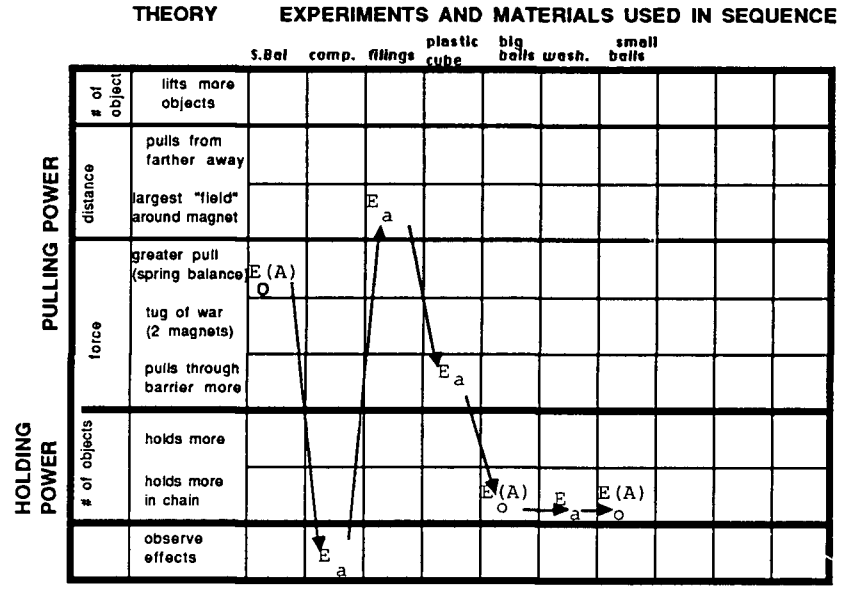


Figure 6. Examples of Option Loop 1.

Grade 4



Grade 7



Option loop 1

Option loop 2

or

$E_o(A)$ Experiment with outcome

E_a Abandoned experiment

E_{no} Experiment with no outcome

Figure 7. Examples of Option Loop 2.

addresses student evaluation within individual experiments and across a series of experiments.

Abandoned Experiments

Most likely, all students' experiments provided them with information of some type, however, not all yielded a result where one magnet emerged as strongest. Overall, thirty-three experiments (N=122) were abandoned before students used all three magnets, and twenty-six experiments did not furnish a quantitative outcome (from counting, measuring, computation or estimation) when students used all three magnets.

For grade 7 dyads, half of the forty experiments conducted in Set 1 did not have results. For Set 2, about one-third of the twenty-five experiments did not have results. For grade 4 dyads, slightly over half had no results in Set 1, while less than one-fourth had no results in Set 2. The differences between the two sets is partly due to dyads repeating "successful" experiments from Set 1 in Set 2. Table 6 shows the number of experiments abandoned (students did not use all three magnets) and without an outcome (all three magnets were used with no quantitative outcome).

Six dyads abandoned experiments at some stage. Their talk to each other, and during the interviews, provided some insights into why experiments were not completed. Five of the six dyads stated that they abandoned an experiment because the materials "didn't work" or an expected effect did not result. In subsequent experiments, dyads went on to use the same theory of action but with a different set of materials (Option 1 Loop).

> "They [large steel balls] didn't come up to meet it [magnet], they were too heavy and we used the small ones."

Table 6

Number of experiments abandoned, with no outcome and with outcome

Grade	Dyad	Abandoned		No Outcome		Outcome	
		Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
4	KEV, WIL	16	0	4	1	3	3
4	AMY, JAN	0	0	0	0	2	2
4	JIM, TOM	2	1	4	0	4	5
4	LEA, MEG	0	0	1	1	5	3
Grade 4 Totals		18	1	9	2	14	13
7	ROS, KAY	1	2	0	0	3	3
7	DAN, JEF	5	0	1	0	4	6
7	SUE, ANN	3	0	3	3	7	3
7	JON, ALI	2	1	5	3	6	4
Grade 7 Totals		11	3	9	6	20	16

"That's [small balls] too hard to measure, let's do these [washers]."

"It didn't work [the magnet would not stick to the spring balance]."

"I found the magnetic force wouldn't go through playdough, it totally eradicated the force."

It didn't work because they [magnets] were almost the same [strength] and they could both hold it up."

One grade 4 student talked about abandoning an experiment because of his procedures. "I made a mistake, I forgot to hold down the magnet and see how much [by using the spring balance] it took for it [magnet] to release the washer, how much pressure, then I saw it didn't work." This was the only instance when a student referred critically to the procedures used.

Student Use of Controls During an Experiment.

The variables, distance, number of objects and force were manipulated by students to determine the pulling and holding power of the magnets (to show how far, how many and how much). Students from both grades made attempts to keep the type and number of objects constant. For example, students instructed each other to use the same or identical materials with all three magnets since the washers, nails and steel balls were two sizes. When materials looked the same (e.g. a stack of washers), students assumed that they were the same size and weight. ROS7 explained that if two different sized materials were used, "it would give a false answer." Students consistently used the same amount of materials for each magnet during experiments. The amounts of filings, however, were estimated since individual filings could not be counted.

All dyads noticed the differences in strength between the "sides" of the magnets (the poles of the magnets are stronger). SUE7 talked about the small balls rolling to one side of the magnet and affecting their experiment. Although dyads noticed a difference, none consistently used one side of any of the three magnets or systematically determined which side was the strongest. JON7 concluded that the strongest side of the magnet "changed." LEA4 commented, "It didn't really matter." Using the different sides of the magnets indiscriminately led to variability in the data.

Also regarding the magnets, JAN4 told her partner, "Maybe they [magnets] are all the same [strength] but this one holds more because it's bigger [more surface area]." JAN4 solved this problem by placing the long bar on the magnet and loading each end of the bar with washers, similar to a barbell with weights. KAY7 believed that the magnet could hold large objects better if they were balanced, and she carefully balanced the larger objects on the magnets. KAY7 and ROS7 also spoke about magnets having more magnetic pull in the air than on

the table, "I guess in the air the pull will go out here [moves hands around the magnet]; if it [magnet] is on the table it can't really go like that because the table is here [under the magnet]."

Besides using the sides of the magnets indiscriminately, other factors involving the manipulation of materials contributed to students' variable data. In some instances students' procedures did not match when they worked in parallel on an experiment (one magnet per student). For example, one grade 7 student counted the number of balls (placed all around the magnet) which the magnet held, while the other student counted the balls which formed a chain hanging from the magnet. They either did not notice what the other was doing or did not believe the two procedures were different.

Variable Data

Five dyads obtained conflicting results where two different magnets appeared as strongest. For example, in an experiment one magnet lifted more steel balls and in another experiment, within the same series, the same magnet did not pull an object from the farthest distance. According to ANN7, "They [magnets] have been all good at different things." Three dyads (one from each grade) did not have variable data. Two other dyads did not have conflicting data in one set.

The occurrence of variable data led some dyads to a long series of experiments. For instance, with Set 1, JON7 and ALI7 found that 'B' was "strongest" in the first experiment followed by several experiments where 'A' was strongest. In this series, thirteen experiments were conducted to decide finally that 'A' was strongest. Whereas, KAY7 and ROS7, who did not have variable data, conducted only four experiments where all four showed 'A' as strongest.

Variable data usually occurred early in a single series and may have prompted dyads to change materials and/or theories of action. Most dyads did not speak of being surprised at the variability of the data but a few became somewhat frustrated as they tried to decide which was the strongest magnet.

ROS7: It was kind of confusing because A would pick up some stuff and B would pick up stuff and C wouldn't and C would pick up stuff and B couldn't and we didn't know which was strongest. I think we tried heavier stuff then...we tried all the materials and tried to find which one picked up the most and we put together which one picked up the most washers.

Students most often stated the cause for variation of the data was due to the materials (different materials may yield a different outcome) and rarely mentioned their own methods of experimenting as a cause. The following comments were given by students.

SUE7: It depends on what you're picking up because like the red one [Magnet A] is stronger for some things and the black one for other things.

JON7: Well some [magnets] have different reactions to different metal, I guess some of the materials worked different.

JIM4: Different metals maybe don't put it [magnetic force] through or something."

LEA4: Well, first of all when we tried the balls and the washers, it was different, so it could be different again if we tried a different thing. I thought that with the different materials, one could pick up better than the other one.

Deciding Which Magnet is Strongest

It was difficult to determine, from the sequence maps, how dyads, confronted with variable data, finally decided which magnet was strongest. Three dyads concluded with the magnet which appeared strongest in more experiments. Two other dyads did not. The student dialogues revealed the following strategies used for making conclusions.

1. A competition or "race." DAN7 and JEF7 talked about making conclusions with the following analogy.

DAN7: Let's say you got first place in half of the things and third on all the rest and another person has got second places, the person that got all second places would be the winner because that person was at least good at all things.

JEF7: Let's say you got 3 points for first, [2 for second, and 1 for third]; if you add them all up, the second place would win.

DAN7: It wouldn't work with points for what I am saying, the one who is all around good at everything should get the [first] place whereas the one who is good at one and not another, that's how I decide.

While working, JIM4 and TOM4 talked to each other about their variable data and decided how to make the final conclusion, "OK, we have one more test

and that says the winner." He later said during the interview, "You do it [an experiment] an odd number and the one that wins the most wins." Words such as "win", "lose" and "tests" were commonly used by dyads.

2. Relying on a "hunch." The analysis of students talk to each other revealed their "hunches" about which magnet was strongest during the first and second experiments of the series. In a few instances, students' final conclusion was not the same as their hunch. However in most cases, the final conclusion matched the result of the first experiment. According to KAY7, "[magnet] 'A' was the strongest, we were trying to prove that because we thought 'A' was the strongest because of the first experiment. "

3. Elimination. One magnet in each set was significantly weaker than the other two. Six dyads eliminated a weaker magnet during the series of experiments. "The weak ones are easy to find (JEF7)." Therefore, the dyads worked only with the two stronger magnets. As DAN7 argues, "In this case, you are not finding which is the strongest [magnet] you are doing the process of elimination, and finding the weak ones and that would leave you with the strong one, or if all are the same, you have to do another test." When students eliminated one magnet, the following experiments which used two magnets were not determined as abandoned by the researcher (since they did not use all three magnets).

4. A crucial experiment. A few students attributed a greater significance to one or two experiments in the series. As JON7 stated, "The others [magnets] could not do this [an experiment using a barrier]; it was a really hard test." SUE7 justified a final conclusion by saying, "Well, it [magnet A] won on this [experiment]."

Certainty of Conclusions.

Three grade 7 dyads and all grade 4 dyads came to the correct conclusion in both magnet sets. Seven dyads were asked how certain they were of their final conclusions. Two grade 7 dyads said 100% and the other said about 95%. None of the grade 4 dyads said 100%. Their responses ranged from "over 50%" to 90%.

One dyad from each grade was asked how certain they would be with the results of their experiments in a different context; they were scientists working on the Space Shuttle. The following dialogue came from DAN7 and JEF7.

JEF7: We would do more tests

DAN7: In that case, there is more riding on it and you have to be more careful. You could be 100% sure but you would want to do more tests. LIVES are riding on it or money. If you are wrong then it is all your fault. It is like a basketball game, you psych yourself up for it. If you don't then you are not as ready, or won't do as well. You get set, work harder.

JEF7: You should never be too sure of yourself, or negative, do your hardest.

DAN7: Be under-confident in the space shuttle, so you get more confident.

TOM4, from the grade 4 dyad said, "I would have to be 100% sure." He and JIM4 agreed that a scientist could be 100% sure, "not always, but most of the time."

Students Designing Experiments

At the end of the interview, the researcher asked the students if they preferred designing their own experiments (like they had just done). They said the following.

DAN7: It's more fun doing it this way. It's kind of like being stranded on an island and you make do with the materials.

JEF7: It's more challenging, it was fun with you just giving us materials and we worked with what we had.

JON7: Our own way.

ALI7: The other way [being told] is not fun at all.

LEA4: That you can choose. Like when I was making up my own experiments from stuff in the kitchen. Lots of kids, want to make things, experiment, see if it [water] will overflow and it kind of comes from that.

WIL4: I prefer making our own [experiments] it is more interesting.

AMY4: Make your own, because you can use your imagination and do whatever you want and try things. When you just look in the book it tells you what to do. With lots of materials you can think of things to do that would take hours to make.

JAN4: If you have a book right in front of you, you don't exactly get to think up things. With the box [full of materials] you could do a

whole bunch of stuff but with one [material] you get bored, like if you are in a car and all you have is a book, you can get car sick and not have anything else to do, but if you have games.

Two students talked about not being allowed to experiment on their own.

MEG4: One time I woke up really early and made up an experiment, I put an egg in it and I stirred it in the blender and it all fizzed up and my mom said, "Don't do that." I'm not allowed to use stuff in the kitchen, only like toothpaste and soap.

JAN4: [teachers] want you to do something, you know specific because people might goof off and they want you to get what they want done.

In general, students enjoyed the challenge of the task, and viewed it as a novel experience.

CHAPTER 5

> "Lucretius Carus, the Epicurean poet, deems the attraction to be due to this, that as there is from all things an efflux of atoms into the space betwixt the iron and the loadstone- a space emptied of air by the loadstone's atoms [seeds]; and when these begin to return to the loadstone, the iron follows, the corpuscles being entangled with each other."
>
> - Gilbert (circa 1600) about Lucrecius (95-55 BC)

Discussion of Conclusions and Implications

This chapter includes three sections which discuss conclusions of the three research questions of the study:

1. What knowledge do students use in the action context?
2. What are students' actions in response to the operational question (which magnet is strongest?) with a given set of materials?
3. How do actions and knowledge of students from grade 4 compare with those from grade 7?

Each of the sections is divided into a discussion of conclusions corresponding to the set of specific questions listed under each of the three research question in Chapter 1. For example, "2b. What are the sequence of students' actions?" is the subtitle to a discussion of conclusions of research question 2.

The chapter also discusses: implications for science teaching based on the findings of this study, the utility of the Action Science perspective, and possibilities for future research to explore other dimensions of "Children as Experimenters."

1. What knowledge do students use in the action context?

The designs of student experiments were grounded in their knowledge schemes they judged as relevant to the problem at hand. The knowledge schemes included students' operational knowledge of magnets, their beliefs about how magnets interact with objects, and their notions of strength as a property of magnets. Generally, student experiments involved showing the pulling or holding abilities of the individual magnets to determine their strength.

1a. What knowledge of magnets can be inferred from students' use of materials?

Students' knowledge of what magnets do. The pulling and holding behaviours of magnets are at the root of the language and actions of students while they experimented. The question, "Which magnet is strongest?" cued students to their operational knowledge of magnets. The students' language regarding what magnets do can be categorized into two magnet behaviours. Magnets pull and hold magnetic objects, described by students as "pull", "lift", "move", "pick up"; and "hold", "stick", "carry." The two behaviours are what students observe when they interact with a magnet and object; the magnet pulls the magnetic object and holds it unless the object is too far from the magnet, or the object is too heavy (relative to the magnet's strength).

Students notions of strength as a property of magnets. Magnetic strength, for the students, was generally associated with the pulling and holding "power" of the magnets. Students measured the distance from which a magnet could pull an object or the number of objects a magnet could hold. Students determined the strength or "power" of the magnets from these measurements. The determination of magnetic strength from an observable effect (the magnet holds a number of objects) is similar to what Andersson (1986) refers to as Experiential

Gestalt Causation (EGC). For example, "the greater force exerted by the agent, the greater the effect" may translate to the greater the magnet's strength, the greater the number of objects it can pull. Andersson also cites distance as a common type of EGC. In this case, the effect on the object increases or decreases as a function of distance between the agent (i.e. magnet) and the object (i.e. washer). Andersson's notion of EGC is similar to what Benbow (1988) describes when students equate magnitudes of non-observable components of phenomena to what is observed. In the case of magnets magnetic strength is equated with how much a magnet can hold.

The sizes and weight of magnets. Students discussed the size and weights of the magnets to each other while experimenting ("Which one is heavier?") and during the interviews ("I thought it [the strongest one] would be the biggest one"). The belief that the large or heavy magnet may be more powerful is similar to what diSessa calls phenomenological primitives, simple abstractions based on phenomena. diSessa (1983) proposes levels of priorities of such abstractions. Two context-dependent levels are the cuing priority and the reliability priority. The former regards how profitable the concept (i.e. size) appears to be in the situation. Once cued, "the resistance to abandonment" is the second level of priority. For the students of the study, attention to size was likely cued by the magnets' disparate sizes. The priority of size appears to have been abandoned by students since they did not select the largest magnet as strongest, and their conclusions were not justified in terms of magnet size. LEA4 made the comment, "There are different kinds of magnets, one could be bigger, but not more powerful." During interviews, several students gave counter-examples to the notion that "larger is stronger" (e.g. a small amount of nuclear explosives is stronger than much more dynamite). ANN7 said, "Usually people would say

the biggest is strongest, but not necessarily." All but one dyad concluded that the smallest magnet was the strongest with Set 2 magnets.

Weight was given a higher priority than size by students. Several students talked about a magnets' weight as they discussed their data: "Well usually the heaviest one is the strongest"; "If it was heavier, it had more pull." There was no obvious difference between the weight of the two strongest magnets in Set 2 but a few of the students decided that the magnet they chose as strongest was probably the heaviest also. In Set 2 one magnet was light in weight and students were immediately suspicious that is was a weak magnet.

Conclusions for 1a: Students' experiments embodied their operational knowledge of magnets: magnets pull and hold some metal objects. Magnetic strength was distinguished as the pulling and holding "power" of the magnets.

Students associated a magnet's weight with its strength, where heavier means stronger.

1b. What knowledge of experimenting can be inferred from students' sequence of actions?

"More is better" is a common theme. During a series of experiments, students changed materials and theories-in-use frequently and commented that doing more experiments gave them more information. Those dyads who generated variable data conducted a large number of experiments without replications. Although students believed some metal objects "react" differently with magnets, they did not use the same objects with different theories-in-use in consecutive experiments (i.e. keep the materials constant and change the theory) but opted to change materials. Also, in the case of variable data where two

magnets appeared as strongest, students conducted more experiments to break the "tie." The magnet that "won" the most experiments was designated the strongest.

Students manipulate variables. Students assessed the strength of magnets by measuring and comparing *how many* objects a magnet could pull or hold, and *how far* away a magnet could pull an object. That is, in different experiments students manipulated the number of objects and the distance between magnets and objects to determine the pulling and holding abilities of the magnets. The students sought to recognize the strongest magnet by showing an effect (the magnet pulls or holds objects) that could be assessed in terms of relative quantities. KAY7 elucidates this point as she reflects upon her experiments, "It's just a plan of how to work it. If you think about magnets, what magnets do... and how can we show which magnet is strongest." Most often the strongest magnet was distinguished by the greatest number of objects pulled or held, or by the greatest distance from which an object was pulled.

In addition a few students manipulated force by placing an object between two magnets and pulling magnets apart as in a tug of war. The magnet which could hold the object (or greater number of objects) after the magnets were pulled apart was deemed stronger. For example, a grade 4 student told her partner, "Let's put the nails on one side [of the magnet] and see if it can hold them while another one [second magnet] is there pulling." These students and others do not mention the force of moving the magnets apart, but focus on which magnet pulls the object from the other. One student, DAN7, manipulated force using the spring balance by pulling the spring balance and the magnet (adhering to a washer hooked onto the spring) apart. During the interview, DAN7 explained that he was not trying to weigh the mass of the magnet but measuring the pulling power of the magnet by using the spring balance.

In *On the loadstone and Magnetic Bodies and on the Great Magnet the Earth* (circa 1600) Sir William Gilbert (in *Encyclopedia Britannica,* 1952) explains how to find the strongest loadstone. The similarity between the following description, written almost 400 years ago, and the student experiments in the study is striking.

> A strong loadstone sometimes lifts in air a mass of iron weighing as much as itself; a weak loadstone hardly attracts a bit of fine wire. Those, then, are the stronger loadstones which attract and hold the larger bodies... All loadstones are tested for strength in the same way, *viz.*, with a versorium (rotating needle) held at some distance; the stone that the the greatest distance is able to make the needle go round is the best and strongest. Bapista Porta also rightly determines the power of a loadstone by thus weighing in a balance. A piece of loadstone is put in one scale and an equal weight of another substance in the other, so that the scales are balanced. Then some iron lying on a board is brought nigh, so that the two bodies cohere perfectly their points of attraction; into the opposite scale sand is poured gradually till the scale in which is the loadstone separates from the iron. By weighing the sand the force of the loadstone is ascertained. So, too, we can make experiment and find the stronger stone by weighing sand, if we put in a pair of scales loadstones that balance each other. (p. 56)

Like the student experiments, the three ways presented by Sir William Gilbert involve assessing a magnet's holding and pulling abilities by manipulating objects and distance, and measuring its magnetic force by using a scale. They are, perhaps commonsense ways to determine magnetic strength with simple objects.

Students used non-magnetic objects as barriers to "block", "slow down", "eradicate", "dilute", "weaken" the magnetic force. This concept of magnetism holds that non-magnetic materials affect the behaviour of the magnet. Students identified the strongest magnet as the one that can still affect an object or set of objects with a barrier in place. Students did not systematically alter the type or number of barriers. The manipulation was in using different magnets with a particular non-magnetic barrier and finding how well the magnet could penetrate the barrier. No students mentioned that the barrier increased a distance between the magnet and the object.

Similarly, an elementary teacher who also performed the task with similar materials used plastic chips between the magnet and magnetic object and wrote the following: "I used the plastic chips as insulators between the magnet and a washer, gradually adding the chips until one magnet wouldn't move the washer." The notion of an insulator may have been cued by the plastic chips, where the teacher applied an existing scheme, what insulation does (i.e. with electricity), to magnets. JEF7 made a similar conjecture, "The wood would probably slow it [magnetic force] more or stop it; wood is an insulator."

Students Control Variables. In this study students did control variables that they believed would affect the outcome of an experiment. For example, when students manipulated the number of objects, they ensured the objects were the same in kind and size. When distance was manipulated, students were careful to place each object and magnet in the same "starting position." In "Science at Age 11", Harlen (1985) discusses students' design and performance of investigations, based on data obtained from an extensive set of instruments developed by the Assessment of Performance Unit. She states that the students, "...in their investigations they will control as variables in a 'fair' test those things which past experience suggests to them may affect the result" (p. 158).

Some students noticed as they experimented that the "sides" of the magnets behaved differently. For example, small steel balls quickly moved to a particular side of the magnet, or some sides (magnetic poles) "worked" better (held more objects). Still, students did not systematically pursue these findings. Some claimed the strongest side changed. The interviews with students indicated they knew little about magnetic poles. Similarly, Gammon's (1988) study of grade 5 students showed their lack of knowledge regarding the magnetic poles. Millar and Driver (1987) discuss the influence of students' knowledge on their experiments,

> ...the process of experimentation depends on the learner's prior knowledge. The way an experiment is undertaken, the factors which are selected for investigation and those which are controlled are not objective features but derive from the experimenter's mental representation of the situation in question. (p. 50)

Conclusions for 1b: Students manipulated variables to show an effect which they judged as data. Variables included the number of objects, distance between magnets and objects, and force.

Students controlled variables they believed would affect their outcome, however controls were limited by their domain-specific knowledge.

1c. What Knowledge of Magnets is Elicited During Students' Reflections about their Actions?

Students use situation-specific explanations. Students depicted magnetism with a variety of terms, such as energy, power, rays, electricity, suction. The three models presented in the study represent ways in which

students envision magnets attracting objects. The Pulling Model is dynamic whereby the magnet directly affects the object, pulling it from a short distance. This phenomenon is explained in terms of the behaviour of the magnet; it "pulls" or "sucks" causing a nearby object to move. The Emanating Model is also dynamic such that the magnet emits something ("unseen rays" or "energy") that interacts with the magnetic object, causing it to move towards the magnet. Like Andersson's (1986) elements of EGC, the agent, (the magnet) with the help of an instrument (invisible 'rays') affects the object. The "unseen rays" are an abstraction that serve to explain an effect students observe. The model appears to be based upon the notion that non-magnetic barriers placed next to the magnet block or "slow down" what comes out of the magnet. Students also used this model to explain the way magnetic objects form a chain and hang from the magnet whereby the magnetic force "goes through" each object to the next. The Enclosing Model was described by one student, DAN7, as a force that surrounds the magnet. When an object is within the circle of "force" it is pulled to the magnet. DAN7 recounted "waves" around a magnet like a picture he had seen in a book. At an explanatory level, DAN7 assimilated his interpretation of that picture into a scheme which predicts, like the Emanating Model, that wood or plastic can block the force. Unlike other students, DAN7 attempted to 'show' the circle of force with iron filings and measure its strength using a spring balance.

All three models explain the movement of a magnetic object placed near a magnet. The Pulling Model is the simplest of the three, and is distinguished by its correspondence to simple, observable magnet behaviours. However, when students observed or 'felt' an effect which this model did not explain they invoked an emanation model that incorporates an instrument (something beyond the magnet) which still may be thought of as suction, or "stream", but can penetrate some barriers. For the students, the Emanating Model explains a

situation they observe: the magnet appears weaker (does not pull an object) when the barrier is placed between the magnet and object. Concomitant with this causal inference, is what students 'feel' beyond some barriers, reinforcing the idea that something comes out of the magnet and goes through some barriers. For example, on two occasions, KAY7 used two metaphors to explain two different effects: a dental suction straw that lifts water from above for a magnet pulling an object from a distance; water coming out of a hose that is partially blocked by a finger for a barrier blocking magnet "rays." Students' explanations with non-magnetic objects, generated explanations based upon an emanating model. That is, it appears that students did not envisage something coming out of the magnet in the absence of a barrier. Students used two models to explain the interaction between a magnet and an object, one model for magnetic objects and another for non-magnetic objects. These student explanations were *ad hoc* as they attempted to explain what they believed to be disparate magnet behaviour with particular objects.

Similarly, in work done on students' conceptions of light (Rice & Feher, 1987; Feher & Rice 1988; 1989) students were found to explain effects (shadows, images, coloured objects) involving various types of light sources differently. Feher (1988) explains,

> The simplest explanations offered by the children focus on the material object only, without involving the receptor or the light. In these first level explanations, the actual colour, the image and the shadow of the object, just like its shape or texture, are taken to be properties of the object itself.... If, as we have done in our work, the light is dramatized (by making it intermittent, or extended or coloured) the observer cannot easily dismiss the role played by the light and has to acknowledge its

> significance. This leads to second level explanations where the light is attributed dynamic properties: it acts on the object and in fact makes the effect. For example, coloured light can change an object's colour or it can cause the object to emit a shadow in the colour of the light. In a later stage, when the children no longer invoke dynamic properties for the light, there still remains a teleological element: the light beam goes in a preferred direction that is determined by the problem at hand (e.g. forwards, to my eye, to the window). (p. 4)

In the present study students used situation-specific reasoning to explain magnet interactions with magnetic and non-magnetic materials. Two different situations cued different priorities of what was explained, leading to more than one model of how magnets interact with objects. For example, the magnet "sucks in" and the magnet "emits rays" through a barrier. Claxton (1983) posits that students construct mini-theories in order to make sense of new situations. Mini-theories are defined by the situation and therefore limited in their ability to unify related phenomena. William, Hollan and Stevens (1983) talk about the use of multiple models by subjects in their study. The authors state, "The subject often appeared to use more than one mental model to answer questions. He shifted models when one would provide an answer but no justification or when a bug or ambiguity occurred in the model he was using" (p. 148).

Conclusion for 1c: Students used multiple models of magnetism to explain effects they observed. Such explanations are likely students' attempt to make sense of what appears to them to be a new situation and a different magnet behaviour.

2. What are Students' Actions in Response to the Operational Question (Which magnet is strongest) with a Given Set of Materials?

Dyads conducted a series of experiments whereby they manipulated different materials in a variety of ways and used specific strategies to compare the results. Dyads did not repeat experiments to confirm or disconfirm results. Generally, they argued that variability of data was due to the peculiarities of the metal objects.

2a. What theories-in-use can be inferred from students' actions and their reflections of their actions?

Theories of Control. The designs of student experiments were grounded in their knowledge of what magnets do and their conceptions of 'strong.' Both contributed to a theory of control (their hypotheses) that informed what students did and how they interpreted the outcomes of their experiments. Generally, the student experiments involved determining the pulling or holding "power" of the individual magnets, for example, by showing that one magnet could pull more objects. According to Argyris et al. (1985) people, in an action setting, select a manageable set of causal theories constructed from experience (If I do *a*, then *b* will occur) that can be applied to the situation. Furthermore, these theories often prescribe 'how to' achieve intended consequences. An integral part of a causal theory is an expectation of what will happen following particular actions, such as "If I put a magnet near a pile of washers it will pull them." Causal theories are implicit in theories of control. For instance, the theory of control "The strongest magnet will pick up the most washers" presupposes the magnet will pull washers from close range. A theory of control, or hypothesis is specific in that it

informs an individual what to do concerning the problem at hand, e.g. finding the strongest magnet.

Theories-in-use. In this study, the researcher inferred theories-in-use (referred to as a theory of control from the actor's perspective) from student actions. Within experiments students manipulated the number of objects, distance and force in a variety of ways which are represented by nine theories-in-use reported in Chapter 4. They involved either the pulling or holding "power" of magnets. The researcher constructed theories-in-use in a form that states the effect that distinguishes the strongest magnet, such as "The strongest magnet will hold more objects."

In an attempt to work together student partners often made their theories explicit by telling each other their "idea" prior to starting the experiment (See Table 4 for examples). Students expressed distinguishing factors such as "how far", "how much", "how many" in order to communicate the particular quantity sought to distinguish the strongest magnet. For example, a student said to her partner, "Get the nails. Let's see how many it [magnet] can pick up" JAN4. The students lowered each magnet over a pile of nails and counted the number of nails attracted to the magnet. The theory-in-use inferred is, "The strongest magnet will lift more objects."

Conclusion for 2a: Nine theories-in-use were inferred by the researcher. Embedded in the theories-in-use are particular magnet behaviours (pulls, holds) and the distinguishing factor which determines the strongest magnet (i.e. greater distance, more objects).

2b. What are the sequences of students' actions?

Students change materials frequently. All dyads conducted a series of experiments with each magnet set. Sequence Maps of dyads' experiments show they consistently changed materials or added new materials to those previously used with each new experiment. Although students initially were told they did not have to use all the materials in the box, some dyads employed nearly everything during a long series of experiments. The following suggestions are given as to why students changed materials frequently.

1. Students' believe that various materials, because of their size, mass or composition may yield a different result for the same procedure. During interviews students stated that different materials "work" differently with the magnets, "Well some [magnets] have different reactions to different metal" (JIM4). Gammon's (1988) study also showed that grade 5 students were unclear about which metals are attracted to magnets.

2. A more discriminating material is required based on the previous result. Often, students found no difference in holding or pulling abilities of two magnets and chose new lighter objects. Also, rulers were added to a set of materials when estimation was difficult or viewed as inaccurate.

3. Materials influence what students do. Materials may cue an idea for a new experiment. Therefore a change of materials during a series of experiments may be due to a new experiment which requires particular materials.

4. Students are curious about how some materials behave near magnets. The compass was an object of student curiosity. Some dyads observed the effect of a magnet near the compass, and later incorporated it into an experiment that manipulated distance (how far away could a magnet affect a compass). The students were also very curious about the filings, especially when they were taken out of the jar and held by the magnet.

5. Some students may believe that they should use all the materials presented. Student beliefs about what they should do cannot be discounted.

Students change theory of control. During the analysis of a dyad's series of experiments, the researcher defined an experiment as new by a change of materials or theory-in-use by the students. Sequence maps (See Figure 6) show patterns of such changes as well as changes of what was manipulated (e.g objects, distance or force). At times during a sequence of experiments, dyads continued to use one theory-in-use for several experiments, only changing materials. For example, students manipulated the distance by lowering the magnet towards a washer and estimated how far the magnet could attract the washer. Subsequently, the students repeated the procedures with a steel ball and measured the distance with a ruler.

A change of materials only may be implemented for the reasons discussed in the previous section. This sequence of changing materials only is called the Option 1 Loop and was implemented at different times during the series of experiments (See Figure 5). Only one dyad used this option throughout an entire series with one magnet set. In this option, a new set of actions are implemented with new materials in the service of the same theory of control and the same interpretive frame. That is, the outcome of an experiment is interpreted in the same way or frame as the previous experiment (i.e number of objects held) only the materials have changed. Argyris, et al. (1985) describe this action as "more of the same."

More frequently however, students changed the theory of control as well as materials. In this case the students are re-planning what to do by selecting a new theory of control or interpretive frame, and in some cases a different variable to manipulate. The outcome may still be interpreted in terms of "how many" but the intended effect has changed (from how many balls are lifted, to

how many balls are held in a chain). A change of the theory-in-use is called Option 2 Loop.

Choosing a new theory of control may be a result of more than one of the following factors.

1. Two students work together. At the onset of the task, each student may generate a different frame because of different causal theories or different materials they notice. Therefore, each student may initiate a new experiment at different times.

2. The effect that a student or students anticipates from an experiment was not achieved, prompting students to try something new. Students often talked about an experiment as "not working" which may have resulted in an abandoned experiment or a completed experiment which did not yield an outcome.

3. Students are confronted with variable data. The majority of dyads obtained variable results usually between two magnets which were close in strength. Generally, these dyads conducted longer sequences of experiments where the frequency of Option 2 Loop was high.

4. Trying "different things" is viewed as collecting evidence. For some dyads, considerable data were collected. During interviews, students talked about the necessity of doing many experiments "to be sure." These students used strategies for dealing with variable data, such as which magnet "won" the most "tests."

5. Students attempt to find reliable experiments. Dyads who abandoned a large number of experiments, appeared to be searching for a reliable experiment or set of experiments which may have prompted manipulating different variables.

Students abandon Experiments. Close to half of some dyads' experiments did not have quantitative result, where one magnet appeared as strongest (almost exclusively with Set 1 magnets). In these cases students abandoned experiments before all three magnets were used, or they used all three magnets but no distinguishable outcome resulted from the manipulation of materials. However, this does not mean that students did not gain information from their actions.

Generally, students stated that they abandoned experiments because they did not "work" due to the materials (e.g. the ball "rolls" to one side of the magnet) or the effect; "We thought some of them [experiments] would work differently than they did." Although is is not clear exactly why some experiments were abandoned or what they revealed to students, these short-lived experiments showed that students constantly monitor their actions. It appeared as if they knew quickly (before all three magnets are used) whether or not an experiment would provide the information they sought.

Students' talk showed they anticipated a particular magnet behaviour at the onset of the experiment. For example, one student tells her partner, "Let's see how many nails it can pick up." She assumes the magnet will pick up some nails, and the girls look for how many are picked up. If the quantity cannot be determined for whatever reason, or the magnet does not behave as expected, the experiment is abandoned. One pair of grade 4 boys decided to see how long each magnet could hold a steel bar. "Let's see which can hold this bar the longest." Within a few seconds ("one-Mississippi, two Mississippi...") the boys discovered that the magnet never dropped the bar and the experiment was abandoned.

Conclusions for 2b: Students changed materials with each experiment and changed theories of control (Option Loop 2) frequently during a series of experiments.

Students monitored individual experiments and abandoned those which did not provide the information sought ("it didn't work").

2c. How do students reach a conclusion?

Students make measurements. Dyads measured the number of objects a magnet could pull or hold and the distances from which magnets could pull objects. In one case, force was measured using a spring balance. When students manipulated force in the tug of war or barrier experiments the number of magnetic objects that magnets pulled or held were measured. In the language of the students, measurement involved distinguishing "how many", "how much", and "how far." Measurement consisted of estimating the number of objects or distance, counting the number of objects, computing the number of objects as a subset of a large number, measuring linear distances, and in one case an attempt to calculate the area of a pile of filings. In most cases the greatest number of objects or distance usually indicated the greatest magnetic strength.

However, during many dyads' experiments two magnets appeared to be equal in strength or an individual magnet was strongest in only some experiments. The occurrence of variable data was usually a consequence of inconsistent use of the poles of the magnets, inaccurate estimations or measurements, or procedures that were performed differently for each magnet in an experiment (especially when each student worked with one magnet).

Variable data. When confronted with variable data some dyads (from both grade levels) employed a competition strategy to make a final conclusion.

In a series of experiments the magnet that appeared strongest in more experiments was said to be the "winner", or strongest. In the interviews, a few students compared this competition strategy to their own experiences in track and sports tournaments where the winner is "better at more things." JIM4 recalled that he and his partner conducted an odd number of experiments to implement this strategy. In their case a "play-off" experiment decided which of the two magnets which were "tied" was strongest. Similarly, in the pilot study a grade 7 dyad assigned points to experiments and tallied them at the end of the series.

Such a "decathlon" strategy, employed by these dyads, is better understood when the following student views are considered.

1. Different materials may behave differently with the magnets (students are unclear about metal objects and magnets).

2. Different effects which are observed are viewed as distinct behaviours of magnets (i.e. holding, pulling), thus a magnet may be "better at different things." For example, one grade 7 dyad recalled two experiments. "They were different. He was trying to see how much one would hold whereas I was seeing how much one would pull."

3. In an experiment, students focus on the way the magnets behave and how materials "react" rather than procedures they employ. When faced with variable data, students did not reproduce experiments, but relied on and based their conclusions on what they observed in a given experiment.

Not all dyads who obtained variable data used the competition strategy. A few dyads did not conclude that the strongest magnet was the one that appeared stronger in more experiments. Three other strategies were used by dyads. First, some students relied on a "hunch" or an idea of which magnet was strongest early on in the series. According to KAY7, "[Magnet] 'A' was the strongest. We

were trying to prove that because we thought 'A' was the strongest from the first experiment." Dyads may have attended to data which supported their hunches. It is not clear however how students arrived at such hunches. Second, dyads selected results of particular experiments ("a really hard test"). Dyads who selected a significant set of experiments based final conclusions on them rather than the entire series. Third, the weakest magnet from each magnet set was eliminated early during the series of experiments.

Conclusion for 2c: Students constructed specific strategies to make conclusions. These included elimination of magnets, selection of data based on 'hunches' or 'best experiments' and 'competitions' where one magnet appeared strongest in the most experiments.

3. How do Actions and Knowledge of Students from Grade 4 Compare with those from Grade 7?

The designs and procedures of experiments of students from both grades were similar. The similarity is likely due to common operational knowledge of magnets, a common notion of what indicates magnetic strength (e.g. strong means holds more), the context of the task itself, and students' limited experience with open-ended tasks.

3a. How does students' knowledge of materials and their interactions with materials compare?

Student Knowledge. Three of the grade 4 dyads described the pulling behaviour of magnets as, "The magnet sucks the filings" or the magnet "sucks in." It is not clear whether this term is used merely to describe the object moving towards the magnet, or if the term is used in an animistic way (as a purposive

act). Only one grade 7 student used the term "suction" in a metaphor. Otherwise, the language dyads used to describe magnet behaviour, such as "lift", "pick up" or "carry" were comparable.

Generally, dyads measured magnetic strength by determining the variance of the pulling and holding abilities of the magnets, thus they relied on their knowledge of what magnets do. DAN7 was an exception. He incorporated 'his' notion of a field into two experiments, represented by two theories-in-use that no other students from either grade used: The strongest magnet has the largest magnetic field; The strongest magnet has a greater measurable force. The former embodied DAN7's notion of a circle of force that surrounds the magnet (Enclosing Model) whereby he attempted to "show" the magnetic circle with filings on a paper and a magnet underneath. DAN7 stated, "It was supposed to show the waves of the magnet or how far the force was." His experiment was subtly different from other student experiments as it was an attempt to define the magnetic field (an abstract notion) by showing a pattern of filings around the magnet and measuring the size of the pattern.

DAN7 also used the spring balance to "measure the magnetic force." He stated that he was not "weighing" the magnet, but using the apparatus to measure "pulling power." DAN7 attached a washer to a spring balance and while holding down the magnet he extended the spring to the point where the washer was no longer attached to the magnet. For each of these trials he would read the scale and record something like "$^1/_2$ oz. pull." During the interview, DAN7 had trouble explaining what was going on in the experiment, however he was convinced it was a good one and used it with both magnet sets. He commented, "I am not sure how to explain this, I wanted to see how much it could pull." DAN7 measured "pulling power" by using the physical property of an implement (the compression of the spring) that depends on force. When he

was asked what $^1/_2$ oz. meant he said, "I guess I am seeing how much weight [the magnet can pull] because that's what a spring balance does." The spring balance was not used by other students. One grade 4 student stated that it probably measured temperature.

It is not clear how well DAN7 understands the operation of a spring balance used to measure mass or how he thought it measured magnetic force in his experiment. A pair of grade 10 students (not subjects of this study) who completed the same task using the same materials wrote a description of an experiment they did that matches DAN7's experiment.

> Method: attach the washer to the spring scale and suspend it so that the washer just touches the magnet. Gently pull on the scale and record the forces on the scale when the washer is pulled from the magnet

DAN7's attempt to measure magnetic force is consistent with his attempt to show the magnetic field with filings and measure its size as a way to find the strongest magnet (the larger "circle of force" means a stronger magnet). All other students measured strengths of magnets by how many objects a magnet could hold or pull, cueing on their operational knowledge of magnets. Since students focussed on the number of the objects rather than their mass, it is probable that they did not think in terms of gravitational and magnetic forces.

DAN7 had a broader knowledge of magnetism based on some books he had read. He attempted to use 'his' notion of a field in experiments and explanations. Unlike other students, DAN7 used his enclosing model to explain a magnet's interaction with both magnetic and non-magnetic objects (barriers). He and his partner JEF7 worked individually on many experiments rather than

cooperatively. JEF7 was convinced that DAN7 was trying to weigh the magnet by using the spring balance.

Student Experiments. In general, grade 4 and 7 student experiments were comparable. Between these dyads, seven theories-in-use represented over one hundred experiments. The following reasons may account for similar theories-in-use across all dyads.

1. Students had limited knowledge of magnetism and relied on their operational knowledge of what magnets do; magnets pull objects and hold them. Theories-in-use generally involved these two behaviours.

Beyond this study, the researcher has worked with more students of the same grade levels, grade 10 students, and teachers, using the same task and materials. Common to other experimenters is the tendency to rely on their knowledge of what magnets do. Furthermore, magnet strength is commonly assessed by "how many" objects a magnet can hold, and "how far" a magnet can be from an object and still pull it.

2. The operational question focussed students' attention on strength as a property of magnets, and the notion of comparing the magnets' strengths to determine the strongest. The students appeared to have a similar conception of 'strong.' Such congruence of meaning among the students may be the result of the way everyday meanings of words shape children's ideas or concepts (Osborne and Wittrock, 1983).

3. The finite set of materials that were provided likely influenced student designs and procedures. The non-magnetic materials, for example, were used with one theory-in-use by students. Steel balls and paper clips lend themselves to counting as a measuring procedure.

4. The opportunity to choose materials (from a large sample) and design experiments during an open-ended task was fairly new to all students. They

claimed to have spend little or no time experimenting in school. Therefore grade 4 as well as grade 7 students' overall experience with conducting experiments in school was limited

Conclusion for 3a: In general, the similar language and theories-in-use used by students from both grades indicate they share a common view of the ways magnets behave. However, one grade 7 student, who had a broader knowledge of magnetism, used two theories-in-use that no other students from either grade used.

3b. How do their sequences of actions compare?

Students did not appear inhibited by the task or the conditions in which they worked (e.g. video camera, observer). In fact, the researcher was surprised at the immediateness of dyads' initial experiments. A quick, indicative statement, such as "I've got an idea...," and a brief plan between partners usually preceded a dyad's swift manipulation of materials.

Set 1. The grade 4 dyads conducted a total of forty-one experiments with Set 1 magnets. The number of experiments for each grade 4 dyad varied considerably, from two experiments to twenty-three. Therefore, sequences of experiments, variability of results, and number of abandoned experiments differed among these dyads. Dyads from grade 7 conducted a total of forty experiments in the first magnet set. The number of experiments per dyad ranged from four to thirteen.

Set 2. With Set 2 magnets, grade 4 dyads conducted less than half the number of experiments as Set 1, from two to six experiments per dyad. Also, fewer experiments were abandoned or yielded no result. With Set 2 magnets, three grade 4 dyads used Option 2 Loop exclusively (change theory of control).

Similarly, grade 7 dyads conducted fewer experiments with the Set 2 magnets (about one third less). They also abandoned fewer experiments. All grade 7 dyads used both Option Loops at some point in the Set 2 series.

For both grade levels, the difference between the number of experiments conducted and abandoned between the magnet sets suggests the following.

1. Students required time to explore the materials. More experiments that explored the effects of magnets on materials (Theory-in-use #9) were conducted with Set 1 magnets.

2. The first magnet set was partly a learning experience for some students whereby they incorporated their findings of what "worked" and what "didn't work" with Set 1 materials to Set 2 materials.

The overall similarities of procedures within experiments and sequence of actions throughout a series of experiments between the grade 4 and 7 students may be due to their minimal experience with experimenting. That is, the sum of experience in designing and conducting experiments for grade 7 students is probably not much different than the grade 4 students.

Conclusion for 3b: The sequence of actions of students from grade 7 were similar to those of grade 4 students. The similarity may be partly due to the students' minimal amount of experience with experimenting.

Implications for Elementary Classrooms

The nature and value of laboratory activities have become the subject of increasing critical analysis. Two issues for research and science teaching related to laboratory activities outlined in the first chapter of this thesis were:

The utility of a "recipe" approach to teaching the processes of science or the demonstrate theories.

The neglect of personal knowledge that students bring to laboratory activities from their prior experience.

These issues are addressed by the study as it explores students' actions and knowledge in an open-ended task. The following are implications based on the study for elementary science teaching.

Students Designing Experiments Without a 'Recipe' to Follow

The students of this study were innovative and enthusiastic during the task. They generated data and made conclusions. Furthermore, during the interviews students were able to reflect upon the purposes and procedures of their experiments and the strategies they used to reach a conclusion. The findings of this study support the claim that students in the intermediate elementary grades are certainly capable of designing and conducting experiments and should have the opportunity to do so as part of their school science experiences.

"More is better" is a common theme for students. The theme "more is better" was apparent in dyads' series of experiments. From a pedagogic perspective, an interesting consequence of this theme was that dyads used a variety of strategies to find the strongest magnet (Option 2). Approaching a problem from different perspectives is an effective element of problem solving. In the classroom, traditional science activities based on a set of procedures, however, do not allow students to consider alternative ways of solving problems. Moreover, recipe-type procedures are often presented to students as algorithms with the reasoning behind the method absent. An implicit message to students from this traditional format is that the 'right answer' is obtained from one set of procedures. Such a format leads students to doubting their own judgements, and it also leads students to a static view of scientific inquiry. In

contrast, the induction of young students into the world view of science should highlight the message that critical and creative thinking are important attributes of scientific inquiry.

During interviews, the students from both grades were able to distinguish between the task they had just completed and 'textbook' tasks. According to JAN4, "If you have a book right in front of you, you don't exactly get to think up things." AMY4 communicated the same feeling as she summarized why she liked the task with magnets, "Because you can use your imagination and do whatever you want and try things. When you just look in the book it tells you what to do." All the students in this study were enthusiastic about the task and stated they preferred choosing materials and conducting their own experiments.

"More is better" should also be a theme for teachers to consider as they plan science activities. Students need plenty of time to explore available materials prior to open-ended tasks. In this study students were not alloted time to manipulate objects before the onset of the task. With the first magnet set, students conducted almost twice the number of experiments than they did with the second set of magnets. Of the first set of experiments more were abandoned and more were conducted to explore the effects of magnetism on objects.

Also, science teaching should provide students with numerous opportunities to design and conduct experiments wherein they build a wide repertoire of experience with experimental procedures which they can further develop over time. Ward (1979) comments about young students experimenting,

> Elementary secondary physics books provide only a limited account of magnetism. The 'essentials' are reckoned to be a brief history of magnetism, the importance of the compass in navigation, magnetic and

non-magnetic materials, and the Laws of Magnetism, and a simple look at magnetic force fields. All these important ideas are fascinating enough, but fostering a leisurely and playful familiarity with magnets reveals so much more. It is the details in physics - as in all science - which most excite a sense of wonder. the details are not necessarily difficult to see, if habits of careful observation are encouraged and pursued. There is time in primary schools to appreciate such 'little things.' But theories to explain them can wait. (p. 439)

The Influence of Student Knowledge on Science Activities

Causal Theories. The interplay between student knowledge and action has important implications for laboratory activities. Causal theories which students bring to open-ended investigations prestructure what students believe to be relevant and how they interpret what they observe. Hence, what students attend to likely conforms to expected outcomes. Students encountering an unexpected effect often abandon their experiment, claiming it "didn't work" due to the peculiarities of different metal objects. For example, students were surprised that some "sides" of the magnets "worked" better than others (e.g. pulled more objects). However, students did not pursue this outcome further but disregarded it.

In science teaching, what students notice and attend to during a science activity can inform the teacher as to what they know about the materials, or what they do not know about the materials. For example, while working with an eight year-old child and magnets, Ward (1979) observed the following,

...I noticed that - while connecting a train of clips behind a magnet - he [student] said, 'I wonder if the power lasts.' When no extra clips could be

taken along, he answered himself by saying a definite 'No.' Then he intrigued me by clustering all his clips near the magnet's end, and said: 'So I'll put them nearer the magnet.' (p. 433)

Control of Variables. Generally, students controlled variables that related directly to what they manipulated, rather than considering any intrinsic properties of magnets or other materials. For example, when students manipulated the number of objects, they used objects of one kind (e.g. all small balls). However, students did not consistently use the same side of the magnets (i.e. poles) to lift or hold objects which, in many cases, led to variable data. However, interviews indicated students knew little about magnetic poles. Thus, the control for the sides of magnets would not likely occur to students.

Science curricula often label the control of variables as a science process skill. , In this case, the term "skill" is used loosely and communicates a message to teachers that the control of variables can be taught and transferred unproblematically by students to different contexts. However, it is not reasonable to expect students to initiate or understand certain controls in open-ended investigations when their knowledge of the materials is limited. Moreover, controls in student experiments are determined partly by properties students attribute to the materials being used.

Mini-theories. The use of non-magnetic materials generated student explanations based upon an emanation model. Students who previously talked about magnets "sucking in" stated that a plastic square blocked rays coming out of the magnet. They also explained that magnetic power "travels" through magnetic objects held in a chain. Students' explanations of various effects were *ad hoc* (for a specific case) and represented diverse ways of thinking about how

magnets interact with different objects rather than one encompassing view of magnetism.

In science teaching, one goal is to move students from mini-theories towards more fundamental scientific theories. Such a move means the abandonment or reformation of an existing theory. Current research, however, shows student theories to be tenacious as they are based on their everyday experience. One condition to encourage change in student thinking is the use of frequent counter-examples which may act to encourage the students to examine the generalizability of their existing theory. Thus in science teaching, it is important to expose students to conceptually related phenomena to provide a rich apperceptive background from which students organize conceptual schemes. diSessa (1983) argues that the difference between the novice and the expert is not so much the character or content of knowledge but the organization of knowledge. The expert has a large set of contexts that cue fundamental ideas rather than situation-specific ones.

Often in the science classroom, where time and equipment are limited, teachers demonstrate or ask students to perform one or two experiments with the intent of illustrating to students fundamental science concepts or theories. One or two experiences will not likely stimulate conceptual change, nor restructure conceptual relations to extend to a range of phenomena. At the risk of covering less curricular material, laboratory activities should extend students' experience with related phenomena. Woolnough and Allsop (1985) make the following suggestion,

> It is clear that the science teacher's task is to arrange appropriate experiences for the student in a range of contexts, so that the student is

able to build up personal constructs which will lead on to increasingly meaningful learning. (p. 35)

The Use of a Constructivist Perspective: Action Science

In science education, one direction of research has focussed on student thinking about a range of natural phenomena which are usually topics included in science curricula. Such research is grounded in the assumption that individuals actively construct knowledge from their interactions with the environment. These studies have shown that students have indeed constructed beliefs about natural phenomena prior to formal instruction. Results from these studies have been used to generate instructional models and strategies for teaching scientific subject matter to students. Within the genre of research on student conceptions, fewer researchers have examined the interplay between student thinking and student actions while they are engaged in problem solving activities with materials. Studies on students designing and conducting experiments, for example, provide insights into the knowledge students use (i.e. procedural, propositional) and how it is used (i.e. generating hypotheses, interpretations). While 'knowledge in action' research provides insights into the student as experimenter, it also has pedagogic implications for teaching scientific processes.

Within research that carries a constructivist banner and focuses on the nature of the learner, most often researchers ask students to verbalize their predictions or explanations of a particular phenomenon. In this study, student models of magnetism constructed by the researcher came from a careful analysis of the students' observable actions and their explanations and reconstructions of their procedures and intentions.

This analysis provided a comprehensive perspective of the students' knowledge in the domain of magnetism and elucidated the logic of elementary students' actions as they framed the task, planned experiments, monitored what happened during the experiments and made conclusions. Thus the analysis within this study, guided by the theoretical propositions found in Action Science, focussed on students' problem setting and their interpretations of results in addition to students' overt manipulation of materials. Students' causal theories or knowledge of what magnets do (pull and hold), how they framed the problem and what they attended to were inferred from the data and related to the propositions of Action Science.

Future Research

Each dyad's set of actions and interviews was analyzed as a case study. Students' knowledge, beliefs, interactions, and manipulation of the materials lent uniqueness to every case. However, each case study added to the rich character of 'elementary student experimenter' represented by the amalgamation of cases. Consider, for example, DAN7's Popperian view of scientists trying to prove each other wrong, and JIM4's decathlon strategy for making a conclusion.

The following are ideas for further exploration involving children and magnets that could be compared with the present study, in order to explore other dimensions of Children as Experimenters.

1. The Question - The nature of the question posed to children in open-ended investigations may be significant. The operational question posed to students in this study focussed their attention to comparing particular magnet behaviours. It would be interesting to examine experiments where students generate their own questions to investigate regarding magnets.

2. The Materials - The finite number of materials presented to students may cue them to particular procedures or hypotheses (theories of control). Another study could allow students to choose the materials to be provided for the same task. How do students proceed with materials they select?

3. The Students - Grade 4 and grade 7 (intermediate) students were involved in this study. It would be interesting to work with primary students with the same task. It is likely that primary students have used magnets either at home (in toys or on the refrigerator), or in school. Grade 4 students in this study spoke of magnets "sucking in" objects. This researcher is curious to know if very young students believe magnets are 'alive.'

4. A treatment - The influence of knowledge on student experiments appears to be significant. It would be interesting to examine how students perform the same task immediately after a unit on magnetism.

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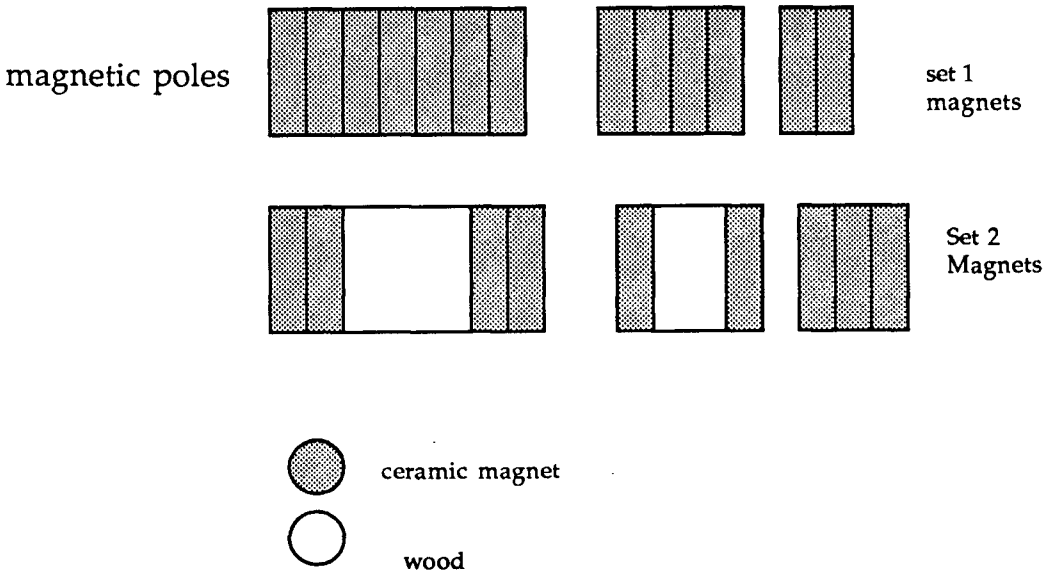
Appendix A.

Composite Magnet Construction



Appendix B.

Materials for Event I

Compass

Iron filings

Large rubberband

Nails (large and small)

Pad of paper

Paper clips

Pencil

Plastic square

Plastic vials with (caps for balls, washers, nails, filings, paper clips)

Plasticine

Ruler

Spring balance

Steel balls

Steel cubes

Steel washers (large and small)

Appendix C

Example of a Transcription of a Grade 4 Dyad for Event I and II

Kev4 and Wil4, Event I April 30, 1990

Wil comments that the microphones may be affected by magnets

Wil grabs the compass right away

Wil: This will connect and if it [mag] is powerful enough it can break it [compass]

Kev: Would a magnet affect my watch do you think?

Interviewer: No I don't think these will

Wil: This is a solid piece of .... [plastic]

(Kev lifts metal bar with A mag)

Wil: This one isn't quite powerful but it [mag B] can stand the stuff up [filings] like hair. Yep, I can move it [refers to needle on compass] I can move this thing sort of , yep I'm moving it

and I can take up the hair on the side [filings again]

I can make it all go up but, it's not quite.....

This magnet [B] is quite powerful , it can move it [compass] still [there is plastic square between magnet and compass] with the glass on

Kev: This one is quite big [A] so it might be pretty powerful

Wil: What is the mass of this [gets spring balance]

Kev: Course it would depend upon the way... Oh, I have an idea

Wil: If this could work I would be sure it is the strongest [puts plastic square on top of vile with cap on, and magnet on top of plastic]

Kev: I wish this was magnetic metal here [puts magnet on spring balance]

that way we could hook it and see which one is the farthest before it comes off.

Wil: Are we allowed to take any of this out

Interviewer: Yes

Now let's see(takes out filings and puts them on top of plastic square]

Kev: Let's see the highest

let's try that

Wil: It is growing hair, mutating [filings on magnet]

Do you have something that I can use to get it [filings] off, too?

Kev: Maybe the pencil, you could scrape it off

This one from this height [picks up filings with A magnet and notes, mentally how high it was]

Now, its growing hair

(puts iron bar to filings, then picks filings off bar, then reaches for pencil to scrape filings off)

This will never work, how do you get that stuff off

(both boys are standing and working)

Wil: What is this stuff?

Kev: Is this stuff hard [plasticine], all right it's not hard yet

Oh, it's plasticine, no wonder it's not hard

Wil: OK, is this possible, it could be possible to create a diversion

Kev: You are mumbling to yourself as if you are Mr. Scientific

(Wil puts steel ball, large one, on magnet and lowers ball to compass)

(Wil sets down compass and puts balls on magnet}

(Kev hooks plasticine on spring balance and metal bar to other end of plasticine)

Wil: Yes this is quite strong

Kev: OK this will take it too one hundred.....

(Kev dismantles spring balance)

Wil: Now watch this, (hooks plasticine to sb and tries to attach magnet to sb)

Which one do you think might be the strongest?

Kev: Try from further

See how far it can

Hey if we had this [steel ball] in the center (of the magnet) where would it roll to?

(Wil now tries to use rubber bands and sb)

Kev: It should work

(Kev gets the ruler out of the box)

(Kev measures.... rolls ball in between A and B magnets)

(The magnet sticks to A)

(Kev gets out sb and puts a magnet on each end, C and B, then abandons)

(Wil has stacked B and C on top of plasticine and lowers down to loose filings and notices strings of filings)

It can pick up other ones [more filings]

Kev: I know it travels

(Wil takes off magnet from plastic and filings fall)

Kev: this one will hold two ball berrings , how much can the others do ? (A)

This one can hold up tow

(Wil tries other magnet B)

Kev: Look that has two going together

(B won't take a third one)

Kev: OK, these two are tied

Kev: Magnet C is the weakest (won't hold two)

Wil: I need magnet C for a second

(Puts magnet on filings which are on plastic square)

I can make some sort of moving picture

Kev: It's not a creature Wil

Wil: Look, Kev I can move it around and now I will try it without C (He had two magnets stacked together)

Now I can move it around, but some falls off

Kev: I've got an idea

Which of these two can lift the most sand up

Wil: Let's sort of lift it up a little bit

(both boys are standing again)

(Wil puts another plastic square on top of filings which are on top of plastic square)

Wil: put another glass square on

It can puck up some with two shades of glass

Oh, God, yours is probably better (A)

Kev: Let's build something

We have more exactly ... with the sheet there (puts vials around sheet of plastic and then puts second plastic square on top of vials and magnet of not of it)

(filings are on bottom sheet of plastic)

(two magnets are tried)

Wil: Oh, Kev, I moved the can (vile) right out of there (vile has magnetic material inside)

Kev: I've got an idea

(Kev sets down ruler, places steel ball about one third up ruler, moves magnet toward the ball from end of ruler, all in horizontal plane)

OK, this started at the nine point mark, wait a minute we can't do this , I just forgot, I have to start over again.

This is at the 11 point mark, this is at the 9 point mark

OK, this one's record is 9 what is this one's record?

ten, oK this one is strongest

Wil: Why do you say that?

Kev: Because this one is the furthest back to pull this

ball berring along the ruler

This one was 2 cm back

What are you doing, making a statue

Wil: No, I am picking things up and seeing how good it is

Kev: Now we'll have fun getting this stuff off [filing?]

I think the red one is the strongest

What do you think Wil

Wil: Probably, I want to try

(gets out small balls which go all over table)

(puts them back)

Kev: I've got an idea

we could use the compass

Wil: Use C

Put B down and C over there (the compass is in between B and C mag)

Kev: Oh, yea

Wil: Now which way is the strongest pull coming from

Kev: But which way does it normally point?

Which one is the pointer?

Wil: the blue, it's going east

Kev: Wait one [mag] could be farther than the other (from the magnet)

you have to ... I've got an idea

(puts compass next to edge of ruler)

How far away does it take to point?

(they put a steel ball between B and compass)

(W is trying to get filings off A)

Wil: You know those little gadgets that you make faces out of? I bet that it is made of this then

Kev: It's called magnetic sand

(compass is abandoned)

(Now Kev tries to get filings off of A)

(Wil puts B on top of magnet)

Kev: Hey, notice this sand is in long slivers, it's long

Kev: I've got an idea

Wil: OK, put it [mag] on this side (he has B right up against the compass)

What ever side that it will go to (needle)

No, it goes down this side, OK,

Kev: It doesn't work the same every time

Wil: See yours, it did it again

Kev: Let's do it with the ruler

(Puts compass at one end of ruler and magnet A at other end)

It can't pick it up from here

(slides magnet down ruler_

It points straight at it at the 9 point mark

(tries B)

What does this one go for

Wil: I imagine the red one might be the strongest, probably

Kev: This is at the seven (B)

I think the red is the strongest

Interviewer: Do you have a conclusion

Wil: Yes, red is the strongest because

Kev: It's bigger

it can lift more ball berrings and

it is further cause , when it is further this needle pointed at it

Wil: so, the red was the biggest

Set 2 Magnets

Wil: What did the red have

Kev: Red was 9

(Wil writes these results on paper)

They are given the second set

Wil: The C is probably the worst

Kev: Let's do the same experiments

Wil: Nah

This one can hardly pick up anything (B)

(Kev is moving magnet along ruler toward ball)

Kev: This one is has to go all the way to the 10 mark for the marble (steel ball) to come

Wil: A is stronger, B can't even pick up anything

Kev: Is it a magnet

Wil: Yea

Kev: Will it pick up magnetic sand

Yes it is a magnet

Wil: that one is 13 (Wil uses ruler and steel ball)

Let's start from ...

Just a sec, let's do another test

with the smaller balls

Kev: OK, C can pick up two (large steel balls)

C's record is two, B's record is none

(Wil does ruler test with small balls instead)

Wil: B can only do it at about 5

I bet 5 is the closest where it can take just a little ball

Kev: Oh, you know what? These are weak magnets (A and B)

This is smaller but it's stronger (C)

Wil: This one can't even pick up a ball (B)

and this one can't pick up , oh yea it can, only sometimes though (A)

Kev: A and C are the two strongest

How do Wile know which one it is

(Wil is writing on paper)

Wil: According to my calculations

I imagine B is the weakest, A is not as good, and C would be the best

Kev: C, A B\

That is the order

A metal ruler,

We are finished with the second set

Interviewer: The answer is C

Kev: Yes c is the strongest

Event II

Interviewer: I am going to bring over some more materials

Interviewer: how certain are you about your results, from 0 to 100% , on the first one?

Kev: 75

Interviewer: and the second

Kev: A lot, 80

Wil: I say a 90 % or probably C didn't look the strongest but actually B was quite weak

(We talk about the filings on the magnets)

Kev: Did you notice that that is in long slivers

Wil: I would just get another magnet like a normal magnet to suck it off

Interviewer: Stronger

Kev: A magnet this size (large)

Interviewer: show me which is strongest using these materials

Kev: This one can't pick up anything (B on metal plate)

This one can (C) and this one can, it's between C and A

Wil: OK, let's try both (metal plates)

Kev: C can pick up one , A will pick up one

Wil: Let's see how good...

it

Kev: I think these have gotten mixed up, because A is the worst

B and A....

(Kev puts plastic square on top of metal plate and puts C magnet on top)

(Wil tries it with wood)

Kev: That's not exactly worth..

Wil: You don't know

Kev: This with the help of B (C and B)

Wil: No, with the help of A too

Kev: OK, A and B can lift up one also

Wil: But when you take B off, it drops (metal plate)

With the help of B

Interviewer: What do you mean with the help of

Kev: Well, with the other one one there

Wil: With two on there

Kev: C can pick up, not very well

Interviewer: Are these things very useful (plastic and wood)

Wil: The help with C

Wil: The B is weaker so it is more up to the A to do the job (when the two magnets are together)

The stronger one on the bottom and the weaker on the top , so if you take off the top one (he shows it stays)

Interviewer: what does putting two magnets together do

Wil: you can do better magnet tricks

(Kev puts a magnet on either side of metal plate and slides B magnet down)

Kev: The metal is different on each side, so you have to use the same side each time

OK A can lift up on this side and C can lift up on this side (same side of metal plate)

Interviewer: What if I give you this (cube) will that help

Wil: No, how much does that weigh?

Kev: A can pick up

Wil: Let's see the farthest (to pick up cube)

(Try it with one magnet)

It's not so good, C the greatest

Interviewer: Can you feel anything through the plastic

(Wil puts plastic down horizontally, and metal plates vertically on each side and the magnet on top of the plastic)

I will put B straight in the middle

It can't really pull

Interviewer: Does it go through the plastic

Wil: I don't think so

the plastic is thick and there is a few holes there to let some power through, if it was much much more thinner like a paper it could , you could feel the magnetic pull, but not plastic, it is quite hard

Interviewer: What about this (wood)

Wil: I might be able to, (he tries it) you can sort of feel it, it is very light

Interviewer: What does the wood do?

Wil: Probably because it is wood not plastic

Interviewer: What were you saying

Kev: Well it is harder to lift the block off one thing than the other

But it is hard, closer hard for C

(pulls cube off magnets)

Wil: If you put all the magnets together, I imagine you could make a pretty good charge , to see how much it can pick up

Two of these

that might put off a lot of charge to go through there

Can we try it

Interviewer: I'll get the other magnets

Wil: Fit them together as they are

That's the heavy one, there are two C's, And B's

Now lets try to see if we feel a charge

(They can't get the magnets to work at all through the metal sheet, the cube slides off)

Interviewer: You were predicting that it would hold

Kev: Obviously C can stick on

That's strange (the cube won't stick on the other side of the metal)

That's unusual

Now try it

'(tried with magnet and it sticks)

(he tries cube again, and it doesn't)

Wil: Oh,

Interviewer: it is thin

Wil: sometimes it might be too different

too different sides, and I couldn't get the hair off, it was on here and I put the other magnet on the side and it will suck all the hair off

so just when you take the magnet off , it just is like dust, somehow

Interviewer: these aren't too useful (plastic and wood)

Kev: I've got an idea,

You can use this magnetic sand to get , which one does it stick to A or C (puts two magnets with filings together, magnetic wrestling)

Interviewer: So what do you guys think a magnet is

Kev: It's C, more hair sticks to this one

Wil: A magnet is something that uses, I don't know really, maybe some sort of

do you think a magnet can create electricity sort of?

And sometimes I don't know how to explain what a magnet is, it is like a power to create things to come towards it but it can't usually create itself to come towards itself

Kev: Can I use some dust, that's all I need to prove this

Wil: You know who sometimes in cartoons they show the magnet goes shhhh

(hand moves forward like a rocket) magnets cannot usually do that

every thing always comes to them

If it is standing still and can't move probably it can do that

It can't be this far (he goes to the back of the room)

Kev: It depends how strong the magnet is

Kev: More dust sticks to this one C is stronger

Appendix D

Example of a Transcription of a Grade 7 Dyad for Event III

Ros and Kay Event II April 3, 1990

Kay: Can you describe what you are doing in this experiment? [Set I, #1]

Ros: We were seeing which one is strongest.

Interviewer: How can this experiment tell you which is strongest?

Can you describe what you were doing?

Kay: We were putting three metal pieces, and then getting each magnet and seeing how far it was above the ground before it attracted and brought the piece of metal up and touched the magnet. They [metal objects] were all the same size , and the same thickness and weight and the one [magnet] that was highest up while it attracted, was the strongest because it had the strongest pull towards the magnet to bring it [obj] up farther from down. The one [magnet] that you almost had to touch the table didn't have much pull. because it didn't attract it very much.

Interviewer: How does that tell you which is strongest, with this pull?

Kay: Which has the most pull, is the strongest.

Ros: The highest that attracts it

Kay: If you hold it [mag] up here, it attracts it, and is stronger than if you hold it down here.

Interviewer: The highest one is strongest, why is that?

Kay: Because it has more magnetic pull

Stronger

Interviewer: More magnetic pull, what does that have to do with how far?

What is the connection?

Kay: It's like if you got....

I guess, If you have the magnet up here and you've got more power, because its' further up.

Interviewer: like anything else you can think of?

Kay: It has more power. ..Ok, let's say you've got a cup of water and you have suction up here, like those suction straws that they have at the dentist, and its up here and it sucks the water up that is probably the strongest than one than if you have to go way down to such the water up.

Interviewer: Ok, a stronger suction you could do it from a greater distance.

Those materials you chose for that experiment. any reason why you chose those?

Ros: They were metal things

Kay: And there were metal squares and little balls.

Ros: and powder

Kay: We used ones [objects] that they [mag] could all pick up at least some distance off the ground and it didn't have to do with balance, that you had to get it perfectly balanced.

Interviewer: Did that first exp. tell you what you needed to know?

Ros: Yea, the strongest

Interviewer: Let's see what else is in that set

You are doing something else

Kay: the squares, no the Balls, they didn't come up

Interviewer: Was that the same exp?

Ros: Yes

Kay: They [large steel balls didn't come up to meet it [mag], they were too heavy and we then used the small ones.

Interviewer: So you repeated what you had done before, why did you get new materials?

Kay: To try to prove your theory again. Try to reassure that what you hypothesized and proving your theory

Interviewer: What was your theory, can you put it into words?

Kay: That the strongest, the one that came up farthest to meet it, what I was saying before, is the strongest, how you are trying to prove which is the strongest

Interviewer: What you were trying to prove is the one with the greater distance..

Kay: That's right, there is also something else that A [mag] was the strongest, we were trying to prove that because we thought A was the strongest because of the first experiment. So, there were two things, the main things is to find out which was the strongest but also proving our theory again.

Interviewer: You both thought A was strongest pretty quickly.

So, you did the same thing with new materials, why didn't you just use the same materials?

Kay: You can get more information and you could... the experiment may turn out differently, if you use different materials you never know, different kinds of material may be different. You use different materials to prove your theory and all different

These are circles

Interviewer: This is the third experiment (back to tape) Those are the balls

Kay: The big ones didn't work

Interviewer: What is this idea about repeating something? (repeat of an action)

Kay: It is like when we were using different kinds of stuff to experiment with, it's like repeating the same experiment over and over again to prove it, that's what we did to make sure we got it right. So we did it three or four times.

Interviewer: Rosamand, you had to be real still holding your hand, that was difficult, did you trust your hand?

Ros: Yes,

Kay: What we did was , I held it there and Rosamand measured it. Then I would do it again and see if it was the same measurement and if it wasn't we did it a third time and see if that measurement matched.

Interviewer: You were using your eyesight. When it became close, in the second set, you were comfortable with your eyesight.

Ros: Yea

Kay: Well we did use a ruler for measuring

Interviewer: Any reason why you didn't move the magnet on the ground towards the object and not in the air?

Kay: I didn't think of it.

Interviewer: Would that result in the same way?

Ros: Maybe, I'm not sure

Kay: I guess the air, the magnet has the pull out here (moves hands around magnet) the pull will go out here, if it's on the table, it can't really go like that, because the table is here.

Interviewer: If it's in the air you have the whole magnetic pull?

Ros: yea

(tape)

Interviewer: That was one cm?

Ros: Yea

Kay: I started here (points to bottom of ruler)

Interviewer: This idea of bringing in the ruler is interesting, why was the ruler helpful.

Ros: To measure the height. To see how each one [mag] pulling object was different.

Interviewer: Now you have a number for each one, what do you do with those numbers?

Ros: Compared them

A was the strongest. The one with the highest number

Interviewer: I heard you say point three. You actually could tell that close

Ros: Yes

Interviewer: did that make you feel any differently

Ros: We had more proof

Interviewer: Why did you change materials there?

Ros: Because they [metal balls] were too heavy. And you can't get a pull

Kay: It [object] kept going to the side of the magnet and It might effect how much distance.

Interviewer: do you know why that is?

Kay: No

Interviewer: Do you think magnets are the same strength on all sides?

Ros: Might be

Kay: Is there something inside a magnet? Well if there is something inside there and let's say its' long here, then the center is strong, and stronger on these sides [long sides] than these sides.

Interviewer: What do you mean something inside?

Kay: Well I don't really know what a magnet is.

I noticed that the one that had the most strongest had the most weight. A [mag] had the most weight in the first one and C in the second.

Interviewer: Did that give you a clue. Or what did you think?

Ros: If it was heavier, it had more pull

Interviewer: Does that influence your decision?

Kay: Yea you might have that theory, again, you think this one is strongest so you set out to prove that it is the strongest, and you find the other is stronger but your mind is set on that one; but I thought that it would be the biggest, A was the biggest [set I] and so I thought the biggest would be the strongest but it [set 2] was the smallest.

Interviewer: Did it surprise you that the smallest was the strongest?

Kay: I thought it [strongest] would be the biggest one.

Interviewer: So you [Ros] were talking about the heaviest one is the strongest and you [Kay] were talking about the biggest one being the strongest.

Kay and Ros: Yea

(tape)

Interviewer: So, that is eight, centimeters?

Ros: no, millimeters

Interviewer: That was one cm

Interviewer: It was important that you did each one in the same way?

Ros: Yea

Interviewer: Was that the third magnet, or are you doing something else

Ros: The third magnet

Interviewer: You both said it was A, how certain were you, 0 to 100%

Kay and Ros: 100%

Interviewer: You used one theory and you did it a couple more times.

Ros: Yea

Set 2 Magnets

Interviewer: did you find the second set more tough?

Ros: no, about the same

Interviewer: You already knew what you were going to do?

Kay: ?

[spring balance]

[the poles]

Interviewer: Rosamand, What are you doing here?

Ros: Seeing if they [mags] could lift the poles.

Kay: We could do the same experiment with then. To see if we could use them for distance, or, it doesn't have to do with which is strongest but we could find if it could carry a long skinny piece, if the weight were distributed different; if that same weight were a metal sheet, could the magnet lift it when it couldn't lift the pole? Or a small block

Interviewer: If that pole was the same weight as the washer, let's say, what you mean is the shape of the object effect it?

(tape)

Interviewer: You didn't like the poles

Kay: It didn't work

Interviewer: You are talking about weight here [video]

Kay: If the washers, let's say, are different weights, one is this thick and the other is this thick, then it is going to be harder to pick it up because it [mag] has to pull more up, so if , ordinarily if it is this thick it [mag] would be able to pick it [obj] up, but if it is this thick it has to go closer to pick it up, it has more weight.

Interviewer: If the washers were two different sizes, and you used them, what would that do?

Kay: Let's use the water suction [metaphor] again, if there's a little piece of rock at the bottom of a container of water, you have to go right practically in the water

to pick it up, it will eventually pick it up but you have to go closer in to get the suction to pick it up,

It's just that the suction is pulling the water up but you have to get closer to get the rock at the bottom,.

That the rock is harder weight. and with the rock you have to go closer to get the rock.

Interviewer: OKay, it's the difference between the weight of the water and the rock

Kay: Yea

Interviewer: Would it be a proper experiment. if you used two different sized objects?

Ros: No

Kay: Not a different weight

Ros: It wouldn't be because it would give a false answer.

(tape)

Interviewer:What are you doing here, Roseamand?

Ros: Taking a piece of metal and lifting the magnet up with it.

Interviewer: Did that tell you anything?

Ros: Yea, the piece of metal didn't pick A and B up but it did pick up C

Interviewer: Yea, that's the second set,

That was an experiment. in itself

Which magnet would be picked up

What does that tell you,the one that gets picked up versus the one that doesn't

Ros: Um, to see which is the strongest, the strongest will be picked up

Interviewer: The magnets were different sizes, did that make a difference?

Ros: No, I don't think so

Interviewer: You had a clue about C then

(tape)

Interviewer: The same experiment. (distance)

Ros: we were using the little squares

Interviewer: Here you were going to write something down, why is that?

Ros: The distance

Interviewer: this is nine mm.

That was the little magnet C

It looks like that B was a real dud

So, right now C is the strongest

(filings) did you ever play with that before?

Ros: No

Interviewer:Do you know what that stuff did?

Ros: It sticks to the metal

It looks like hairs or icicles

Interviewer: It's hard to get off the magnet

Are you experimenting with this stuff?

Ros: We were just finding out what it is

Interviewer: Why is it so hard to get off?

Ros: Cause it sticks on

Kay: You have to break it off

Are you as confident in your answer as in the first set?

Ros: I would say so

Interviewer: In this set, what was it that made you decide that C was the strongest?

Kay: First there was the experiment of picking up the metal blocks and then the other ways we did.

Interviewer: If we go back to Rosamand's experiment, what theory would we come up with?

what did you have in mind?

Ros: I don't know

Kay: Maybe there would've been a difference between the magnet and the little squares, it is a reversal of pulls (pull up mag, with object).

Interviewer: You used the materials I gave you, that plastic had holes in it, could you feel anything

Ros: NOt really

Interviewer: Rosamand said she couldn't feel anything with the wood, what's the difference between the plastic and the wood?

Ros: It's thinner

Interviewer: What is thinner have to do with it?

Ros: It can come easier through, the stream of pull.

Interviewer: If the plastic were the same thickness, without the holes, would it be the same.

Ros: I think so

Kay: Using the plastic with the same thickness without the holes? I don't know I would have to research it.

Interviewer: What did the holes do?

Kay: Permitted the pull to go through and touch the metal, so it could pull up

Interviewer: Does it go through where there is not a hole, or not?

Kay: I would say it probably does.

Interviewer: One of you felt a little bit with the wood and the stronger magnet

Kay: Yea

Interviewer: Can that tell you anything about strength?

Kay: It can, like using other materials, it's like it can't pick up anything with the wood or plastic in between but you can still feel the pull

Interviewer: so what does the wood do?

Kay: If it can pick up with more weight on, it wasn't to do with which was strongest but it might help test, or give information, the weight had to be even to pick it up, or if it could with more weight.

Interviewer: Could it tell which was stronger by which could pick up more weight?

r: Yea

Interviewer: One of you used the word block, what did you mean?

Kay: I don't think it blocks completely but it blocks the power the magnet has

Interviewer: How does it do that?

Is there any thing else you can think of that is like that?

Kay: It is like a hose, if you put your finger on part of it [the opening] it blocks up the main water stream but some water escapes

(tape)

I gave you the cube here

Did you like choosing your own materials better?

Ros and Kay: Yea

Ros: More choice, you can do more experiments. with it

Interviewer: You did stuff so quickly

What gives you these good ideas, like holding it over and measuring the distance, how did you get that idea

Kay: Uh, it's just a plan of how to work it if you think about magnets, what do magnets do and how can we show what magnets do, how can we show which magnet is strongest

Interviewer: (on audio tape here)

One more thing, lets say the strongest mag can pull at a greater distance, with a mag, do think that pull has a certain distance, does it stop, does it get weaker, how far does it go?

Kay: Well, that depends on the magnet, that's what we tried to find out here, does it stop or do you just not feel it anymore?

I don't know

Interviewer: But the strongest will have a greater distance.

Kay: I don't know how magnets work

Interviewer: would you call all these experiments?

Kay: Yes

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