CHAPTER 3

RESEARCH SETTING AND METHODS

SETTING

This study was carried out in a physics course for prospective elementary teachers at San Diego State University. This course, named "Processes and Inquiry in Physical Science" is commonly referred to as "NS412A," which is how it will be referred to in this dissertation. NS412A fulfills a science requirement for students who intend to enter a teaching credential program in California. This course was used by the CPU project for trial testing of classroom materials and teaching strategies, and the course instructor was closely involved with development of the CPU project and course materials. The unusual nature of this course requires that its goals and methods be described in some detail, which is done below.

The CPU pedagogy

The acronym "CPU" stands for "Constructing Physics Understanding in a Computer Supported Learning Environment." The NSF- funded CPU Project developed an inquiry based classroom framework which is supported by structured classroom activity and computer software. The pedagogy was designed as a classroom learning environment which involves a re-conceptualization of methods and goals of physics teaching and learning (Goldberg, 1997.)

CPU goals

In a CPU course, the content goal of learning physics is balanced with process goals of students becoming more aware of and in control of their own learning, developing more positive attitudes towards learning science, and understanding some of the nature of science, such as how scientific questions are asked and answered. It is intended that students begin to notice their own roles in learning science, and that they begin to think of scientific knowledge not as facts dispensed by a privileged minority but as a consistent and interconnected set of useful ideas and methods that people have developed to make sense of their experiences.

The CPU pedagogy is intended to emphasize conceptual development over computations or memorization of facts. Students work in a "guided inquiry" setting, and are expected to develop deep understandings of a particular area of physics. Their work is sometimes similar to doing science. By engaging themselves in making sense of phenomena, students may get a better sense for how science is done, and hopefully develop an appreciation of the nature of scientific knowledge.

Methods of teaching

In a CPU classroom, like in other inquiry courses, the instructor does not "tell" students what ideas to think. There also is no textbook. Instead, the students spend much of their time working in small groups, discussing issues with each other, and the instructor visits the groups and asks useful questions. The instructor also leads whole class discussions on particular occasions. These also offer students opportunities to raise questions and offer possible answers.

The course is based on a learning cycle approach. Ideas are developed over a series of cycles, each of which addresses a particular set of phenomena or a particular set of ideas. A diagram of a single cycle is shown below.

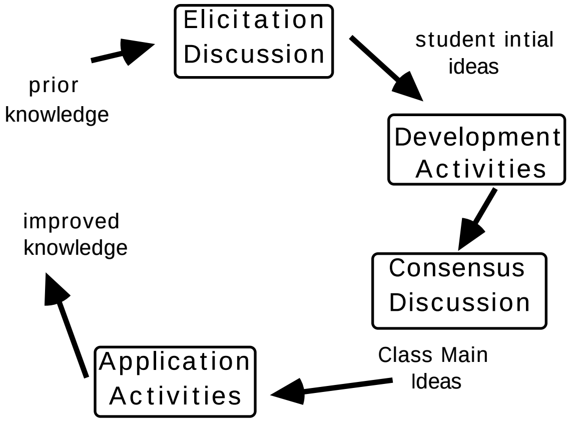


Figure 3-1: A single CPU cycle.

Elicitation

Each cycle begins with an "Elicitation Activity," which involves a whole class discussion of a question or set of questions. The Elicitation is an "unpacking" of student ideas which is designed to make students more aware of their ideas as well as those of other students. It is modeled after Jim Minstrell's whole class "Benchmark" discussions (Minstrell, 1992, diSessa, 1993.) Typically, the instructor asks a question for students to ponder. (Examples from the first two cycles are in Appendix 1.) Each student is first asked to think on his or her own, and to write or draw a personal response on a handout sheet which is provided. After finishing this, students then discuss what they wrote with the other members of their group. The group goal is to come up with a good idea, or the best idea in the group, for answering the question. Each group is then asked one at a time to describe its ideas to the class in a brief presentation. In NS412A, each group drew diagrams on whiteboards that were placed at the front of the room.

Elicitation discussions are intended to raise issues and ideas, not to settle them. Thus the instructor did not judge groups' presentations, and in this class often stood at the back of the room during groups' presentations. The students were asked not to critique other groups' presentations, but only to ask questions of clarification. Groups were expected to critically examine ideas in "Development" tasks which follow the Elicitation.

Development

In the CPU pedagogy, groups spend a lot of time working on Development tasks. Students work through these in groups of three sitting at a computer. The computer documents ask students to make predictions, perform carefully selected experiments, and answer questions that have been crafted to raise particular issues. Sometimes students are asked to construct and/or run computer simulations as well, in the place of experiments or to augment them. The questions that are asked, and the experiments that groups perform, are selected and sequenced to help students develop particular ideas. Each cycle is organized around a set of "target ideas" (that are not presented to the students). It is expected that in working through the CPU Development phase, students will examine their own ideas in detail and extend, modify, or change them as needed. If the course materials have been well planned and the groups and instructor are conscientious in their work, groups will eventually move toward ideas that are similar to the target ideas.

In the Development phase, groups are given the goal of formulating ideas which can explain phenomena they have encountered in the cycle. At the end of this phase, each group contributes written and diagrammed "Candidate Ideas" which are intended to represent their best thinking about the issues in the cycle.

Consensus

At the beginning of a cycle, it is expected that groups will have different ideas. By the end of the cycle, groups' ideas should have many similarities, and a formal consensus of ideas should be possible. To do this, the candidate main ideas from all groups are compiled, discussed, and formalized in a whole class "Consensus discussion."

The goal of a Consensus discussion is for the class to produce a set of idea statements that make sense of the phenomena that have been encountered in the cycle, are supported by evidence, and can be carried forward and used again. The instructor tries to make sure that the ideas expressed in the discussion are similar to the target ideas established for the cycle. The Consensus discussion is intended to have two parts. The first involves students and teacher coming to agreement on a set of statements or "consensus ideas" that will be used by the class. These are based on the groups' candidate ideas. Once the class main ideas have been settled to some degree, the instructor offers expert information in a second part of the Consensus discussion. At this point, the instructor may offer special terminology that the groups may not have invented, or the instructor may offer ways of representing the class ideas in terms of the canon of physics. The instructor tells the class how the ideas that it has generated are similar to those that are found in textbooks, and may offer a more formal version of the class main ideas, and informs the class that those ideas will be used in later work in the unit.

In this class, the instructor sat at a computer in the middle of the classroom during Consensus discussions. A video projector showed a document on a screen at the front of the room, and between periods of discussion the instructor typed statements which ultimately became the Class Consensus Ideas.

Application

After the Consensus discussion, students again work in small groups on "Application" documents, which are intended to help them expand and further develop their understanding of the ideas developed during that cycle, and to explore the utility of these ideas. These Application documents are similar to Development documents, except that they are intended to not raise substantial new issues, but they provide ways for students to use and expand the class consensus ideas. Some Application documents are less structured, and give students opportunities to design experiments or explore phenomena on their own.

The Application phase ends the cycle, and certain tasks sometimes "set the stage" for the next cycle. In Cycle I, the Application phase lasted half of one class period, or about an hour, immediately after the Consensus discussion. Groups worked on one Application document in this hour. In Cycle II, the Application phase lasted one period.

While students might have benefited from spending more time in the Application phase, the instructor had reasons to move on to the next cycle.

Student and instructor roles in a CPU classroom

The CPU pedagogy requires that students express their ideas frequently, as it is expected that the students, not the instructor, develop and present physics ideas. Thus both the students and the instructor must take on roles that are different from those in traditional physics courses.

In the CPU pedagogy, the instructor has three important roles. The first is that of adjusting the cycle structure and/or raising issues, based on his or her impression of the students' understanding and their current needs. This might involve modifying some documents, deciding when to schedule them, and deciding whether to share other groups' results or do a demonstration for the class.

The instructor's second role is that of moderator of class discussions. During these discussions, the instructor often focuses attention on students' ideas, and refrains from offering his or her own views of physics content topics. He or she may offer perspectives on *processes* of physics - what makes a good model, how one evaluates evidence, and may also offer advice on how to perform experiments, or repeat particularly difficult experiments for the class. The instructor can raise topics of class discussion by bringing attention to particular things that students say or particular features or experimental results, and discourage other topics by not attending to them.

The instructor's third classroom role is that of helping groups of students to examine their own thinking and come to their best ideas based on their current knowledge and experiences. When students ask "Is this the right idea?" the instructor might refer to experimental results or interpretations that other groups reached, or offer ways for the group members to test their ideas. The instructor's objective is to place students in a position of "increased scientific power" from which they should be able to critically evaluate and improve their ideas. If the class is successful, most or all groups will propose candidate ideas that are similar to the target ideas.

However, the instructor does give specific advice on how to build models, and provides clear criteria that acceptable class ideas will have to satisfy. For instance, in the magnetism cycles studied in this dissertation, the instructor provided the students at the end of the second cycle with a list of magnetic phenomena that their model of magnetism had to explain. While interacting with students, the instructor also had in mind the ideas that students were expected to develop in the cycle, and may have chosen to give particular types of guidance that could help the students move in an intended direction.

The students play important roles in a CPU course as well. They have the job of (collectively) coming up with models and statements that can explain phenomena that they encounter in the course. To do this they not only have to follow the directions in documents and perform experiments carefully, but they also must express their thinking to fellow group members, examine each others' ideas, and usually come up with new ideas that are useful. They have to make sure that what they are doing and thinking makes sense and fits with other things they know.

The actions of both students and the instructor influenced and were influenced by the roles they assumed. Other features of the CPU pedagogy, such as the learning cycle structure and the computer documents, also influenced classroom roles and actions. This dissertation can't examine all of the influences in the classroom, but it will detail two: how social norms and small groups' construction of responses influenced the development of models of magnetic materials.

Software support

The CPU documents that guided students' work and provided places for groups to add text and pictures were written in Dock'em™, a product of Metamind Software.™ Dock'em™ is a page layout software program that works in the OpenDoc™ environment. OpenDoc™ is a component software architecture that allows users to very easily construct documents with a wide range of functionality. Dock'em™, which was developed to be used in the CPU Project, allows users to place text, drawings, bitmapped pictures, and other OpenDoc™ objects anywhere on a series of pages. Groups working on Development documents are expected to type text, make drawings, and place pictures in responses to questions and other requests in the documents. Dock'em™ makes these tasks relatively simple for students to accomplish.

Groups also use specially designed computer simulation software for part of two Development Activities in Cycle I. This simulator, designed by the CPU project and constructed by Physicon S. C.®, shows idealized static electric and magnetic phenomena. While simulation software was used in other ways in Cycle III and in other CPU Units, it was simply used in Cycle I to allow students to check their observations of particular static electric and magnetic phenomena by comparing them to the simulated results.

Groups can also take pictures of simulators and portions of their documents using a screen shot utility. They place these pictures in appropriate spaces on the document pages.

Course particulars at SDSU

The NS412A course taught at SDSU was scheduled to meet twice each week for 2 hours and 20 minutes per session. This was normally enough time to work through one or two Activity documents. Typically, the instructor talked to the whole class for the first ten to twenty minutes. He always introduced the tasks for the day, and sometimes discussed or showed groups' results from the previous day's work. The rest of the class time was normally spent by students working through Development documents, or on Elicitation or Consensus discussions.

In this course, students were asked to write a half page or so of their own thoughts at the end of every period. These "daily journals" were handed in to the teacher, who read them, sometimes wrote responses, and handed them back the next class period. Students used these journals in various ways. Some used them as a way to communicate with the instructor. Some used them as records of their ideas for that day. Some simply wrote down what they did that day. The instructor used the daily journals to get a sense of how the students felt about the class that day, and of what they seemed to understand.

Students also handed in homework assignments on all four days of Cycle II. Two were relatively informal assignments for students to describe their own magnetic models of a steel nail. These were due on day 6 and on day 8. Two homework assignments were handed out on days 7 and 9. A quiz over the first two cycles was given for the first half of the period on day 10.

The structure of the course and the teacher's stated expectations for the students were quite different from what the students expected when they walked into class on the first day. Many of the students were afraid of taking science courses. On the first day, the instructor was very careful to "sell" the students on this different method, and some students wrote in their first daily journals that they were intrigued and hoped that they would enjoy the course. By the end of the period I studied, more than half of the students clearly liked the class, and more students had become willing to participate in whole class and small group discussions. Some students admitted that they preferred being told what to think, but they were in a minority.

Students probably had many different reasons for liking (or disliking) this course. One possible reason for liking it might be that the course structure was set up to provide a "safe environment" in which students' ideas were given importance. The instructor was very skilled in valuing and supporting students' comments. Also, the students were given more freedom (and time!) to consider their own ideas about issues than they would have had in a traditional science course. Another possible reason for liking the course might be that, after the first week or so, students could clearly see that they were making progress (that is, developing understanding) and the challenges they faced were interesting rather than insurmountable. Most of the students accepted and appreciated the CPU strategy.

The Static Electricity and Magnetism Unit

I chose to study the magnetism portion of this unit for two reasons. One is that little is known about how students develop understandings of magnetism. Every topic in physics offers unique problems to learners, and the ideas that students develop about each topic need to be understood in order to inform the development of courses. The other reason for choosing magnetism was that this unit explicitly engaged students in developing formal scientific models, and the process of model development was extremely interesting when the unit was taught in a previous semester. It was clear that the class could successfully develop a robust and powerful model of ferromagnetic materials, and I wanted to explore this process to see "how it worked." It was an excellent opportunity to study the relationships of interactions to the development of models.

The Static Electricity and Magnetism Unit was composed of three cycles. It was taught at the very beginning of the semester, so that Day 1 of the Unit (and of research data collection) was the second meeting of the course.

Table 3-1: Schedule of the Static Electricity and Magnetism Unit

Cycle	Topic of cycle	Duration
Cycle I	Distinguishing similarities and differences between static electric and magnetic effects	5 days (11 hours)
Cycle II	Building models of magnetic phenomena	4 days (9 hours)

Cycle III	Building models of static electric phenomena (not studied)	7 days (16 hours)

The first cycle of the unit was intended to help students identify and generalize similarities and differences between static electric and magnetic effects. While students did talk about models of magnetism in the first cycle, these models were not the focus of this cycle. The goal was for the class to produce statements about the differences in magnetic and static electric *materials*, and differences and similarities in magnetic and static electric *phenomena*. In the second cycle the class developed models of magnetic materials, and the third cycle centered on development of models for static electric effects. During the first two cycles, students made significant changes in their thinking about magnetic materials and magnets. These changes are the focus of this dissertation.

An overview of the course materials in the first two cycles is provided below. It is intended to provide a guide to the issues and questions that the students encountered. It can give a sense of the instructions and goals, but not of what actually happened in the classroom. This give - and - take will be described in Chapter 5.

There is a difficulty with terminology. The computer documents were called "Activities" and are labeled so here. This use of the word "Activity" as a set of questions and tasks in a computer document should be kept distinct from "activity" as the complex set of events and task-oriented interactions in a classroom.

Cycle I: Identifying similarities and differences in magnetic and static electric effects

Purpose:

Experience and some research (mentioned in Chapter II) have shown that students tend to use ideas of + and - charge to explain magnetic phenomena. The CPU SE&M unit assumes that students must clearly differentiate static electric and magnetic effects before trying to build robust models of both magnetic materials and static electric materials. This differentiation is the topic of Cycle I.

Target ideas:

Students entering a physics course may not know that magnets pretty much only attract iron and steel, that magnets have two different ends, and that static electrically charged objects attract pretty much everything that is uncharged. They have to build up a base of experience with static electric and magnetic phenomena to inform and guide their model building in the later cycles. Thus an explicit goal of Cycle I is to come up with generalizations describing both static electric and magnetic phenomena. Target ideas that students are expected to develop include:

- Both magnetized and static objects can cause both attraction and repulsion, but if one end of a magnetized object repels another, the other end of the first magnetized object will attract the same end of the second.
- There is no evidence of two endedness in rubbed static objects, but there are two types of rubbed static objects. Like rubbed static objects repel each other, and unlike rubbed static objects will attract each other.

- Magnetized objects tend to line up pointing either North or South, depending on how they are rubbed with a magnet.

- Both magnetic and static effects occur without objects touching, and both get weaker as the objects are separated more and more.

- There are differences in materials. Magnets seem to influence iron and other special metals while static electric effects are caused by mostly plastics, but affect practically everything.

- Static effects seem to be short-lived, while magnetic effects can last for a long time.

In addition, the teacher must provide some terminology in the Consensus discussion:

- The end of a magnet that is attracted to the geographic North of the Earth is called the north pole, and the other end of the magnet is called the south pole.

The following section describes the Activities that the class worked through, in chronological order.

Day 1: First Elicitation

Elicitation

Purposes:

The purpose of the Cycle I elicitation activity was to introduce the particular issues of the cycle and to "unpack" students' ideas about static electricity and magnetism. Also, the groups shared their ideas, so that all students would have opportunities to hear and consider different ideas. A third purpose was to help students begin thinking critically about their ideas.

Issues:

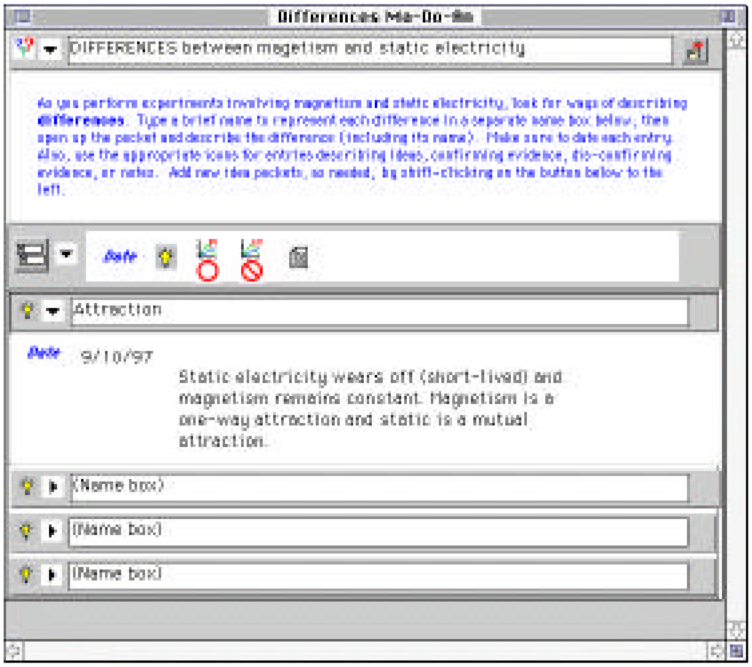
Students were asked to suggest what they thought happens to make a refrigerator magnet stick to a refrigerator, and separately, to make clothes stick together when they come out of a clothes dryer. They were asked to draw pictures representing something that causes these attractions.

Students were also asked to list similarities and differences between static electricity and magnetism. A copy of an elicitation document, filled out by one student, is provided in Appendix 1.

Day 2: First Development work

Activity I-Di Initial Ideas

Groups were asked to write down their initial ideas in "idea container" documents to which they would refer to throughout the rest of the cycle. They first worked through a tutorial on the idea container software. This took longer than expected. As a result, they had limited time to make entries into idea containers. There were two idea containers for each group. In one students were asked to describe similarities between static electric and magnetism. The other idea container was for differences.



DIFFERENCES between magetism and static electricity

As you perform experiments involving magnetism and static electricity, look for ways of describing **differences**. Type a brief name to represent each difference in a separate name box below, then open up the pocket and describe the difference (including its name). Make sure to date each entry. Also, use the appropriate icons for entries describing ideas, confirming evidence, dis-confirming evidence, or notes. Add new idea pockets, as needed, by shift-clicking on the button below to the left.

Attraction

Date 9/10/97

Static electricity wears off (short-lived) and magnetism remains constant. Magnetism is a one-way attraction and static is a mutual attraction.

(Name box)

(Name box)

(Name box)

Figure 3-2: "Differences" Idea Container with one pocket open

Similar to Dock'em™, this idea container document allowed groups to insert text, drawings, or bitmapped pictures into any one of a number of pockets. The intent was for groups to use a separate pocket for each distinct idea.

Asking groups to put their "initial ideas" into idea containers provided groups with an occasion to talk about any changes in their ideas resulting from the elicitation discussion.

The pattern in Development documents:

The Development documents followed a standard pattern: Most introduced a question or a situation and asked for a prediction of what the group thought might happen. Groups were then asked for their reasoning for their prediction. The group was then asked to perform an experiment, record their result, compare their result with their prediction, and offer a new explanation if they had any. This basic pattern varied according to the issues and situation, but was used in most of the documents. Examples of this pattern can be seen in Appendix 1, which presents complete copies of sample documents.

At the end of most of the Development documents, groups were asked to open their Idea Containers and add whatever ideas they felt were important to record.

Activity I-D1 Testing rubbed and unrubbed materials

Purposes:

The goal was for students to find out that only metals (and not all metals) showed magnetic effects, and that a wool-rubbed straw seems to attract all materials, while a magnet-rubbed straw does not attract anything. This was the beginning of helping students to differentiate between static electric and magnetic effects.

Experiments:

Groups used a plastic straw and a steel nail (called "agents") in three conditions: unrubbed, rubbed with wool, and rubbed with a magnet.

They were asked to predict whether and how each of the agents would effect different "victims:" pieces of plastic, wood, paper, aluminum and paper clip. Groups were asked to explain their reasoning for their predictions. They then performed all of the experiments by placing each victim in turn in a "test stand" (a torsion balance made of styrofoam cups, straws, and a piece of thread.)

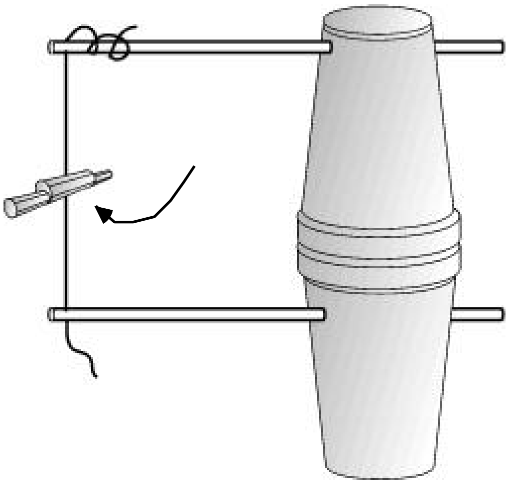


Figure 3-3: Test stand used to test attraction and repulsion

Issues:

Groups recorded the results (attract, repel, no effect) in a table. Follow-up questions then asked groups to synthesize general statements that characterized the behavior of the victims when presented with different agents.

Day 3: Investigating metals and magnetic phenomena

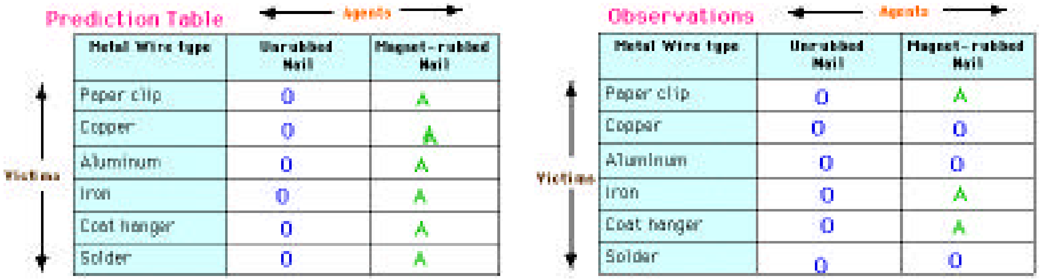
Activity I-D2 Exploring electric and magnetic effects with different metals

Purpose:

This was intended to help groups develop clearer distinctions between static electric and magnetic effects, and to distinguish between magnetic metals and non magnetic metals.

Experiments:

Groups were asked to investigate the wool rubbed straw and the magnet rubbed nail more extensively with five different types of metal wire; paper clip, copper, aluminum, iron, coat hanger, and solder. Below are typical prediction and observation tables made by a group of students for a magnet rubbed nail. The students indicated "attraction" with an "A," repulsion with an "R," and "no effect" with a "0."



Prediction Table

Agents

Victims

Metal Wire type	Unrubbed Nail	Magnet-rubbed Nail
Paper clip	0	A
Copper	0	A
Aluminum	0	A
Iron	0	A
Coat hanger	0	A
Solder	0	A

Observations

Agents

Victims

Metal Wire type	Unrubbed Nail	Magnet-rubbed Nail
Paper clip	0	A
Copper	0	0
Aluminum	0	0
Iron	0	A
Coat hanger	0	A
Solder	0	0

Figure 3-4: Prediction and observation tables for the magnet rubbed nail

Issues:

Groups may have found commonalities in the metals that were attracted to the magnet rubbed nail. They also should have noted that while the wool rubbed straw attracted all the metals, the magnet rubbed nail only attracted a few metals. However, the only type of effect seen was still attraction.

Activity I-D3 Exploring Magnetic Effects and Magnetic Patterns

Purpose:

Groups investigated further properties of magnet-rubbed nails.

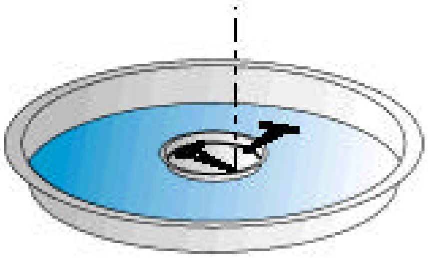


Figure 3-5: Diagram showing how to float and hold nails

Experiments:

Students magnetized a nail and floated it on a coffee lid in a tray of water. They saw that the nail pointed either North or South. They then held first an unrubbed nail, then each end of a magnet rubbed nail near each end of the floating rubbed nail. They then moved a floating rubbed nail around a bar magnet laid on the table, and noted the different orientations of the nail. They also used a computer simulator to do the same experiment.

Issues:

Groups were asked to draw connections between the magnet rubbed nail and a magnetic compass. They also encountered the two - ended behavior of magnet rubbed nails, and found repulsion for some combinations of nail ends.

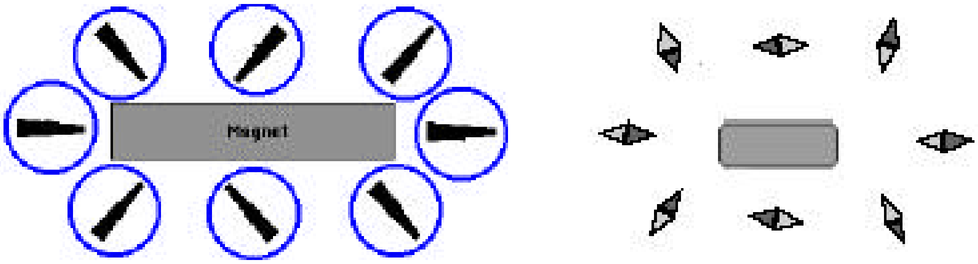


Figure 3-6: Group data (left) and computer simulator picture (right) of orientations around a magnet

Because of technical difficulties and lack of time, the computer simulation part of this Activity was postponed until the beginning of Day 4.

Day 4: Investigating static electric phenomena and Candidate Ideas

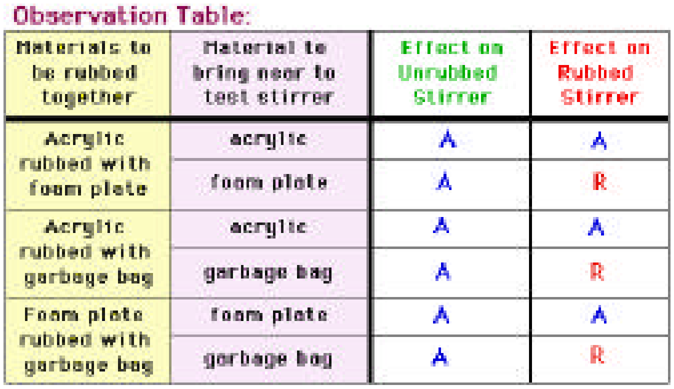
Activity I-D4 Exploring Electric Effects and Electric Patterns

Purpose:

Groups investigated further properties of static electricity.

Experiments:

Groups were asked to rub a styrofoam plate against a sheet of acrylic plastic and note effects on unrubbed and wool-rubbed stirrers in the test stand. They then noted repulsions between two similarly rubbed foam plates. They introduced a plastic garbage bag as a third material (which is intermediate between styrofoam and acrylic in the triboelectric series, an indicator of a material's tendency to grab electrons.)



Observation Table:

Materials to be rubbed together	Material to bring near to test stirrer	Effect on Unrubbed Stirrer	Effect on Rubbed Stirrer
Acrylic rubbed with foam plate	acrylic	A	A
	foam plate	A	R
Acrylic rubbed with garbage bag	acrylic	A	A
	garbage bag	A	R
Foam plate rubbed with garbage bag	foam plate	A	A
	garbage bag	A	R

Figure 3-7: One group's observed results

Finally, groups moved a test stand containing a stirrer rubbed on only one end around a wool rubbed styrofoam cup. They mapped the orientations of the stirrer as seen below.

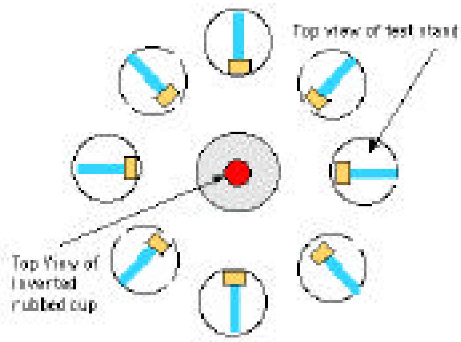


Figure 3-8: Group data of stirrer orientations around a wool rubbed styrofoam cup.

Issues:

Groups encountered repulsion between two rubbed static electric objects. Most groups noticed that when two objects are rubbed together to create static, they will give opposite effects on a rubbed stirrer. They hopefully also noted that static effects don't seem to show the same two-ended behavior as magnet rubbed nails do.

<u>Candidate Ideas</u>

At the end of this period, groups were asked to write their ideas in a Candidate Idea document. They were explicitly asked not to suggest models or explanations of static electricity or magnetism, but just to summarize similarities and differences between the sets of phenomena. Groups were asked to put their candidate ideas under three headings. These are shown below for one group:

Similarities between magnetism and static electricity

1. Both create an effect of attraction or repulsion.
2. Both require the use of rubbing materials before an effect was shown.
3. The force of each effect decreased with distance.

Differences between magnetism and static electricity

1. With static electricity there was always an effect. Although, with magnetism some victims showed no effect.
2. Two rubbed objects in magnetism, attracted at one end and repelled at the other. The two foam plates rubbed separately only repelled.
3. Static electricity has a generalized effect with many kinds of objects. However, magnetism only works with specific objects.

Other ideas relating to magnetism and/or static electricity

We have an idea about the observations of magnetism. The two ends of a rubbed object seem to cause a different effect.

Figure 3-9: One group's Cycle I Candidate Ideas

Day 5: Consensus discussion for Cycle I and Application Phase

<u>Consensus Discussion</u>

The candidate ideas contributed by the ten different groups were combined into a single document and handed out at the beginning of the class period. Students were given some time to look at these before the Consensus discussion began.

The instructor then led a formal discussion in which students were asked to suggest statements and support them with evidence from the class. A number of suggestions were made, and the instructor typed these on a computer whose display was projected at the front of the room. Eventually a set of "Class Main Ideas" was constructed. These are listed below:

<u>Attraction and Repulsion idea:</u> Rubbed electric and magnetic objects can either repel or attract. A rubbed magnetic or electric object will attract an unrubbed magnetic or electric object. Two like electric or magnetic objects identically rubbed with the same material will repel. For magnetic objects opposite ends attract and similar ends repel.

Each Electric object can show either attraction or repulsion, but not both at the same time; whereas the two ends of magnetic objects show the opposite effects (attraction and repulsion).

<u>Distance effects idea:</u> Magnetic and electric effects decrease in strength with distance.

Materials idea: It seems Static electricity can create an effect between all materials, whereas magnetism can have an effect on certain metal objects (for example, contain iron).

Rubbing idea: Rubbing electric objects in any direction can produce electric effects, but rubbing magnetic objects in one direction only is necessary to produce magnetic effects.

Directional pull idea: Magnetism has a directional pull while static electricity does not.

Activity I-A1 Label the Poles

Purpose:

To apply some of the class main ideas codified in the previous discussion. To investigate the effects of rubbing a nail with a magnet.

Experiments:

Groups were to find ways to make a magnet rubbed nail that pointed North or South as desired.

Issues:

Groups found that the direction one moved the magnet along the nail, and the end of the magnet used, determined whether the resulting magnetized nail would point North or South when it was floated and allowed to rotate.

Cycle II: Building a model for magnetic materials and effects

Purpose:

To build models of magnetic materials, and to recognize more features of magnetic phenomena.

Target ideas:

The target model was a simplified version of the magnetic domain model of magnetism. This model claims that ferromagnetic materials (like many kinds of steel) contain many tiny magnets. When an object is not magnetized, the tiny magnets are randomly aligned so that their net magnetic influence averages out to zero. When the object is magnetized, some or all of the tiny magnets point in more or less the same direction, so that their influences together have a sizable result.

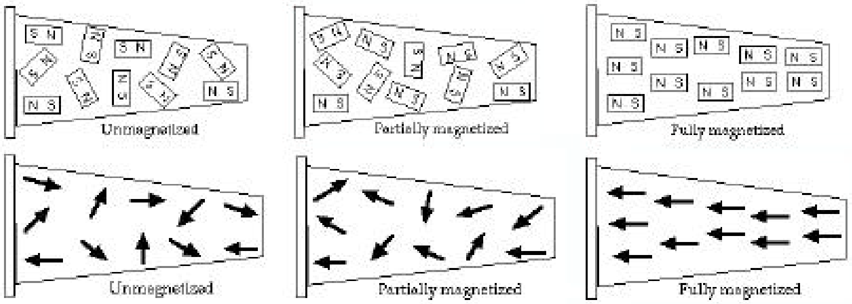


Figure 3-10: Two different representations of the target magnetism model

Another target idea is that two magnets, placed in parallel, will have a larger effect than just one magnet. When the two magnets are placed antiparallel, their influences cancel each other out.

Another target idea is that a larger nail, which contains more tiny magnets, can have a larger effect than a smaller nail.

Day 6: Magnetic Models Elicitation and Development work

Elicitation: What is in a nail?

Purpose:

This Elicitation discussion began Cycle II, and provided opportunities for students to begin thinking about models of magnetism, and for groups to share these models with the class.

Issues:

Groups were asked to remember the experimental results they had seen in previous days in the course, and to suggest their best model for what was going on in an unrubbed nail and a magnet rubbed nail that would account for what they had seen so far.

In an attempt to encourage more careful thinking on the part of students, the instructor handed out the first page of the Elicitation document (on paper) at the end of Day 5, and asked each student to write down her ideas for homework before coming to class on Day 6.

After discussing each of their ideas with each other, groups drew their best diagrams of an unrubbed nail and a magnetized nail on whiteboards. They also wrote down what they considered to be evidence in support of their diagrams. Each group then presented their diagram and evidence to the class.

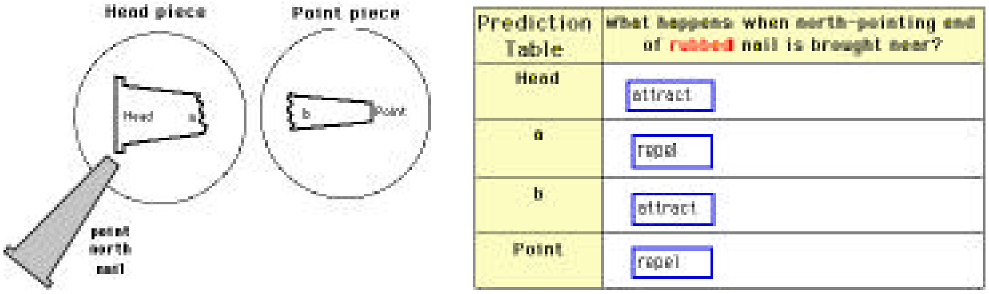
Activity II-D1 - What happens when you break a magnetized nail?

Purpose:

Breaking a nail provided crucial evidence for groups to use in developing more appropriate models of magnetized nails.

Experiments:

Groups were asked to draw on the computer screen their best model diagram of an unmagnetized and a magnetized nail. They then magnetized a "notched" nail that could be broken fairly easily, and after predicting effects, broke the nail and floated each piece on a coffee lid. They were to note the orientation of each piece, and its behavior when a second magnetized nail was brought near each end.



Prediction Table	What happens when north-pointing end of rubbed nail is brought near?
Head	attract
a	repel
b	attract
Point	repel

Figure 3-11: Instructions and prediction table

Issues:

Each piece of the broken nail should have acted like a smaller magnetized nail. This challenged many groups' models.

Day 7: More investigations of magnetic phenomena

Students handed in their first formal homework assignment at the beginning of the period. Handed out on Day 6, it had two questions on static electricity, and four involving magnetism. They were asked to describe two different ways to rub a nail with a magnet to make it point north, to predict whether a bar magnet would attract a piece of paper (and to explain their answer,) to make a prediction involving the two-ended nature of magnetized objects (if one end repels a magnet, what does the other end do?) and to explain what would happen when a wool rubbed straw is held near a non-magnetized piece of wire.

<u>Activity II-D2 Investigating Properties of Magnetism</u>

Purpose:

For groups to develop more experience with magnetism.

Experiments:

Groups used a compass as an indicator of magnetic strength. This worked by placing magnetized objects along an East-West line passing through the pivot of the compass. This caused the compass needle to deviate from its North - South orientation, and the angle of the deviation indicated the relative strength of the effect due to the object.

Figure 3-12: Diagram of the compass setup

Groups measured the effects of size of magnetized nail, of degree of rubbing the nail, and distance from the compass.

Issues:

Groups combined more than one magnet and measured the effects of different relative orientations. Their observations could support ideas about superposition of magnets, which is an important part of the target model. Groups also found that they could magnetize a nail weakly by merely holding it near a magnet. This could enable an explanation of how a magnet attracts to an unrubbed object, but this issue was not raised in the computer document or in recorded discussions on this day.

Day 8: Final Development tasks and Group Candidate Ideas

At the beginning of this period, students handed in a homework assignment on "their best model for a magnetized and unmagnetized nail." They were also asked to show what experimental results they had seen that supported this model.

Activity II-D3 - The Test Tube Magnet.

Purpose:

Groups' work with the test tube magnet was intended to give hints of a magnetic domain-like model in case the class had not yet come up with one, and for groups to gather more experimental evidence.

Experiments:

Groups were given a test tube that was filled halfway with iron filings and stoppered. They rubbed it with a magnet and noted that it behaved like a magnetized nail. They shook the filings and found that the test tube was again not magnetized. They then magnetized a wire nail (round in cross section) and then hit it with a hammer. Its magnetism also decreased.

Issues:

Groups' attention was drawn to the behavior of a collection of tiny metal filings which behaved magnetically like a solid nail. They were also asked to notice what the filings did when the magnet was moved along the test tube. (They flipped over and appeared to align.)

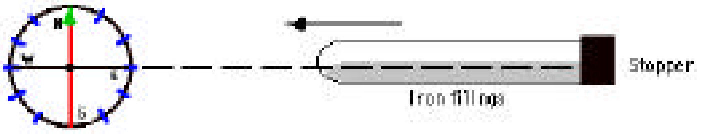


Figure 3-13: Diagram of the test tube and compass

Candidate Ideas

Groups were asked to construct a Candidate Ideas document that showed a picture of three nails: one unmagnetized, one partially magnetized, and one fully magnetized. Next to this picture they were to type a description of it, a set of statements describing how magnetic objects affect each other, and below this, an explanation of how their magnetism model accounted for their observations about magnetic objects. These were printed out and handed to all the students. By this point, all ten groups offered models similar to the target model.

Day 9: Consensus discussion and Application

At the beginning of the period, students handed in homework assignment number 2. It asked students to explain, using their model, how a magnet attracts to a refrigerator. It also asked them to resolve the problem of how a north pole of a magnet points to the geographic north. (The solution is that if you model the earth with a magnet inside, then the North geographic pole must contain a south magnetic pole.) Students were also asked to explain how heating and then cooling a bar of iron while it lies in the North-South direction could cause it to become magnetized.

Consensus Discussion

In the Consensus discussion, the instructor presented a common set of diagrams which represented the kinds of drawings that groups had proposed in their candidate documents. He also proposed the following set of common ideas gathered from the candidate documents:

Fundamental magnetic entities idea: A ferromagnetic material contains fundamental entities, each of which behaves like a tiny magnet (two-endedness). Each tiny magnet can be oriented in any direction.

Magnetic strength idea: The magnetic strength of a ferromagnetic object depends on the number and relative alignment (or orientation) of the fundamental magnetic entities inside the object. The relative alignment of the entities can be changed when another magnet is held nearby, touches, or rubs in one direction the ferromagnetic material.

a. In an unmagnetized object the fundamental entities are randomly oriented; that is, there is no preferred orientation.

b. In a partially magnetized object there is a partial alignment of the fundamental entities; the greater the alignment the greater the magnetic strength.

c. In a fully magnetized object the fundamental entities are aligned in a single direction.

d. For the same relative alignment, the greater the number of fundamental magnetic entities inside an object, the greater its magnetic strength; thus, larger magnetized objects can have greater magnetic strength than smaller magnetized objects.

Magnetic force idea:

A magnetized object will always attract a non-magnetized ferromagnetic object.

Like poles of two magnetized objects will repel each other, unlike poles will attract.

The strength of the magnetic force between two objects decreases as the objects are farther apart.

In the classroom discussion, some students suggested another idea about magnetizing a nail by proximity:

Partially magnetized idea: A ferromagnetic object does not have to be touched to be partially magnetized. The closer the magnet is held to the object, the greater will become the magnetic strength of the object.

These ideas seemed to be accepted by the students. The instructor did not ask for suggestions from students because the models and Candidate ideas proposed by groups were so similar that there seemed to be little point in having groups propose the same things again.

Activity II-A1: Using the Magnetic Patterns Simulator

Purpose:

To give students more opportunities to explore the spatial variation of magnetic "influence" at different points around a magnet.

Experiments:

Groups used the simulator to measure the strength of a magnetic field caused by a magnet at different points around the magnet.

Issues:

The magnet is strongest at its ends, and weaker along the side.

Figure 3-14: Measuring magnetic strength in the simulator

Activity II-A2: Magnetic Objects Simulator

Purpose:

To support the orientation model, and for groups to gain more experience with modeling induced magnetism in objects.

Experiments:

Groups used another magnetism simulator to place unmagnetized objects near a magnet, and to observe the microscopic properties of the objects.

Issues:

Unmagnetized ferromagnetic objects appear to become magnetized when a magnet is nearby.

Day 10: Quiz on cycles I and II

Students spent an hour answering questions about magnetism and their early experiments with static electricity. They were given three major tasks: They were asked to use the class model to explain how heating a magnetized nail can remove its magnetization, they were asked to produce evidence that shows that magnetizing is not a process of transfer, and they were asked to predict the results (attraction or repulsion or no effect) for a series of experiments with different rubbed objects.

STUDENTS IN THE COURSE

As explained above, the students who took this section of NS412A were prospective elementary teachers. Most had very little science experience in previous schooling, and most began the course afraid of science and math courses. Many expressed fears about being able to succeed in the course. On the first day of class, students were given a questionnaire which was used for grouping students together. Two questions asked each student to describe her best and worst science experience in high school or college, and explain why they were the best and worst. About her best science experience, one student wrote: "We did experiments with yeast and baby chicks. The prof made everyone feel involved. I never felt stupid." For her worst experience, this student wrote about her Astronomy class: "It involved a lot of math. The prof just assumed everyone knew and understood. I felt like the only one who didn't understand the concepts or the math."

All but three of the students were women. About ten of them were non-traditional or returning students who were older than typical college juniors and seniors.

All class members

All 31 students in the course participated in the study at a basic level. As whole class discussions were videotaped, all students signed informed consent forms for videotaping and for collection of their work. All the class work that individual students did in the course was photocopied, and computer documents that groups worked on were archived.

Student groups of three members were formed by the instructor, who tried to make sure that each group had students of high, medium, and low academic ability as indicated by GPA. Also, each group contained at least one student who appeared to be expressive of his or her thinking, based on observations made during the first day of class. Below is a seating chart showing where students sat. Some students will be referred to in the analysis chapters and in the Appendices. All of the names are pseudonyms.

Figure 3- 15: Groups in the class (these are pseudonyms)

One focus group

In addition, six students were asked to be in two "special groups" who were to be videotaped as they worked through the computer documents. These were group numbers 1 and 2, shown above. Video data of one of these groups is the primary source of information on student interactions. For an analysis of interactions, video data was only needed from one group, but two groups were selected initially with backup in mind. Because of the importance of being able to observe as much as possible how group members interacted, members of these two groups were selected based on their expressiveness during the first class period. The hope was that these two groups would engage in a lot of discussion, and they did. These six students also satisfied the GPA heterogeneity condition, like the other 8 groups.

These students volunteered to be videotaped. The instructor explained the videotaping on the first day of class, and handed out request forms that asked each student if he or she wanted to take this role. About half of the students in the class agreed to be videotaped in small groups. After choosing members for the two video groups, I telephoned prospective members before the second day of class. All six students said that they were happy to help.

The two video groups sat at tables at the ends of the classroom where there was a little more room for video cameras. These two groups were videotaped while working on Development documents at the computer as well as during the group discussion portions of the Elicitation and Consensus discussions. During Development work, a microphone was placed on top of the computer monitor, and the video camera was placed behind the students. From this position, the camera could see the computer monitor, the experiments that students performed, and most of the gestures that students made to the computer monitor, the apparatus, and each other. Unfortunately, students' facial expressions were normally not visible from this position unless students turned to talk to each other, (which happened quite often.)

The question of selecting one group for analysis was settled at the beginning of Cycle II, when a member of one of the video groups suggested an alignment model of magnetism to her group members. (This was in the Elicitation Activity.) The two other group members liked this model, so the group adopted an alignment model immediately and kept it throughout the second cycle. The other group, on the other hand, struggled with their separation model for a long time before abandoning it on the last day of Cycle II. Because it took a more characteristic (and interesting) model development path, this group was selected for the analysis. These three students are introduced briefly below:

The Three Students:

Marge, an older student, had some formal science experiences many years ago. This student started with more ideas about static electricity and magnetism than her group members, and she seemed very able to reason and articulate her ideas. Marge seemed to reason very quickly and seemed to lead in proposing ideas within the group. Donna, a very tenacious student, worked very hard and did quite well in most of her classes. This class was no exception. She was very consistent in her thinking - once she had elaborated a model of magnetism, she used that model, making only gradual changes, until it was very clear that it didn't work. She often took the role of organizer for the group's work. She also asked questions, and persisted in looking for answers when the other two group members seemed to be ready to move on. Anne, the youngest in the group, did not express her ideas as strongly as her group members. Her statements did not seem to reflect strong commitments to particular models. However, she contributed in important ways to discussions, and influenced the group often by taking either Marge's side or Donna's side when there was a difference of ideas.

The researcher's role

The instructor presented me as a graduate student who would be helping in the class and collecting research data. During most of the class activities I operated a video camera. Another videographer, either a student assistant or another researcher in the class, operated the other camera. We alternated groups each class period, so I videotaped each of two groups five times in ten days. Sometimes I helped other groups with questions, other times the group I was videotaping would turn to me for help. At these times I and the other camera operator were both careful to give responses similar to what other groups might receive for the same question. However, the proximity of a camera operator probably affected the frequency of calls for help by the groups. There is no evidence that this affected the group's discussions in any significant way, however.

RESEARCH METHODS

This section will detail the sources of data used in this research, and explain how various analyses were done.

Data Sources

In each Elicitation, each student wrote on a paper document, and each group drew a single set of responses on whiteboards. The paper documents were collected and photocopied, and the whiteboard work was captured by classroom video cameras.

All of the groups' completed computer documents were collected and archived. There were four Development documents per group in Cycle I and three in Cycle II, and one Application document in each cycle. In addition, groups sometimes contributed to idea container documents (one per group per cycle) and they also submitted Candidate Idea documents at the end of each Development phase. There were ten groups in the class, so one would expect to see ten versions of each Development document, but some documents are missing because of missing students and omissions made by classroom helpers.

Students were asked at the end of every class period to write a journal describing their concerns, a problem, something they learned, whatever was of interest to them. This was intended to occupy the last ten minutes of class, but because they expected to run out of time, students sometimes began writing their journals during slack time in the middle of the course period. Each student received one "course point" for each journal regardless of what was written, as long as it was about something. These daily journals were collected from each student and photocopied.

Students handed in three homework assignments for grading. Two of them consisted of a series of questions and problems similar to questions that would be on the exam. The third simply asked students to describe their best model for what is inside a rubbed nail and an unrubbed nail, and to give evidence that supported their model. These homework assignments were photocopied.

In addition, each student wrote a "Learning Commentary" which was to document a learning experience he or she had in the class. The instructions given in the course syllabus were to

> ". . . write a story telling how you have changed the way you think about a particular idea. Each commentary has three main parts and an appendix. In the **first part** you describe your initial thinking about the idea (at the beginning of the Elicitation Phase). In the **second part** you describe in detail how your thinking changed during the entire Development Phase, and perhaps throughout the Application Phase. You must explain how various laboratory activities, small group and/or whole class discussions, daily journal writing, homework, or personal reflections lead to your changing of the way you thought about the idea. In the **third part**, you must describe your current way of thinking about the idea and compare it (honestly) to the version that has become a class consensus idea."

The above data sources were used to compile information on individuals' and group's models of magnetic materials, and their thinking about magnets. Most of the information on group interactions came from videotapes of the groups at work, plus weekly interviews.

All of the formal work done by the two video groups was videotaped, as mentioned above. Also, whole class discussions were videotaped, as were the instructor's occasional presentations at the beginning of the course periods. The video data provided the main evidence for the development of norms in the classroom, and for the types of student activities in constructing group representations.

I interviewed each member of the video groups individually once per week, for about thirty minutes per session. My goal was to find out how students were thinking, to gather evidence for claims about their models, and to find out how they thought about particular events in the class. However, I wanted to minimize my perturbation of the class so that the data could more closely reflect what might happen in a similar class that didn't have a researcher in it. So interviews did not explore magnetism issues deeply. Because explaining has been shown to be related to problem solving ability in physics (Chi, 1989,) any explanations that students made in interviews could have been learning experiences. Therefore interviews did not probe understanding deeply. Example questions used include "Did the picture Max drew represent what you were thinking?" or "Can you tell me more what you meant when you said....?" or "What changed your mind about what happens in nails?" Questions that probed more deeply than these were not normally asked.

Interviews and a large number of the videos were transcribed, and some of the video was coded using schemes which are described below and in Chapter 5. A variety of data (students' writing, interviews, video data) was collected to support triangulation in the ensuing analyses.

Introduction to the analysis

Terminology

A little bit of language is helpful to describe groups' work at computers or a whiteboard. During the Development phases, groups worked on one computer document at a time. They read instructions on the screen, and they responded to "requests" in the document for predictions, explanations, diagrams, and so on. In the case of whiteboards, the request was spoken by the instructor, and repeated on handouts given to each student. Group members typed or drew "responses." For brevity, the word "response" will be used in this section to indicate "group response."

I will use the word "model" to indicate the group's expressed model of magnetic materials. Most of the time, this was drawn or at least spoken about by members of the group. The term "model" is not intended to suggest a uniform idea used in the same way by each member of the group. It is also not intended to suggest that a single student would say the same thing about magnets in different situations. For instance, if pressed in interviews, different group members might have expressed different details at different time about their "group model." However, the group model, as it was declared "officially" by the group, will be considered a model.

Students discussed other things besides the group model. They came up with modifications to their group model, alternatives to their group model, ways to use their group model in explanations, predictions, experimental techniques, and other things. These various types of physics content expressed in various ways by students were simply called "ideas." An idea as used here could involve physics content or process. An idea about magnetism may have a less formal status, and often a less elaborated relationship to other ideas, than the group model. An idea is probably less complete than the group model.

Three different views:

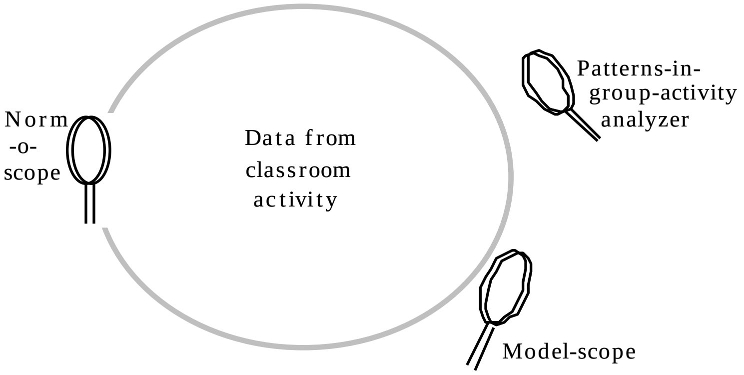


Figure 3-16: Overview of analysis schemes

The data collected for this study was examined for three different kinds of information. First, individual and group models of magnetic materials were collected and categorized. Model categories were invented for this analysis, as Borges and Gilbert's (1998) categories were not sufficiently descriptive or detailed. The "Model-scope" cartooned below represents this process. Then videotapes of the small group discussion were analyzed for episodes when the groups were either typing or drawing responses, or preparing to do so. A set of characteristic patterns of interaction was constructed for these episodes. This is indicated by the "Patterns- in - group - activity analyzer." Finally, video of small group work and of whole class discussions was examined along with paper and electronic documents to generate and substantiate claims about classroom norms. The "Norm - o - scope" represents this analysis. Details about each of the analysis methods are given below.

Research Question 1: Analyzing group models

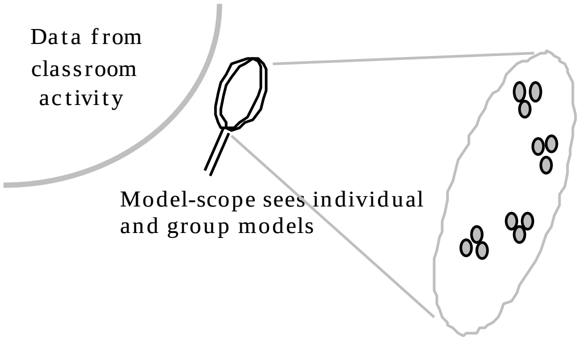


Figure 3-17: Unit of analysis for magnetism models

Information on group models was sometimes available in this class. Groups were repeatedly asked to describe their thinking about magnets and nails. In addition, students sometimes wrote about how they were thinking in their daily journals. The videotapes contributed some information from the two video groups. Most of the model representations were diagrams, drawn by hand or on computer. Sometimes they were accompanied by text.

Because most of information on models was produced by groups, the analysis focused on group models. This is represented in the cartoon above. Each tiny oval in the display represents a student. A cluster of three ovals represents a group.

Despite using the term "model" extensively in this section, I do not claim that students were thinking in terms of models much of the time in this class. Some students appeared to do so, but students and groups generally produced diagrams of models when they were asked to, and they sometimes used models when they were asked to. Whether they thought about magnets in terms of models at other times probably can't be answered by the data. Students could have used something more loosely organized than a model, like remembered experiences, to guide their thinking. The word "model," then, is intended to mean "the diagram and accompanying statements" that students produced at times in the class.

This analysis then is consistent with Hutchins' distributed cognition perspective (1995, pp. 353-374.) The goal of the analysis is not to identify features that are inside individual students' minds, because the models the students produced were cultural products subject to negotiation processes. It could be that none of the students in a group thought about magnets exactly as was represented in the group model. However, the group model diagrams were used in the class as representing the thinking of the group, and they sometimes influenced the thinking of group members, so they were the diagrams of interest to other groups, to the teacher, and to this research.

Categorizing group models

Groups were asked to formally declare models of magnetic materials on five occasions:

Day 1 in the first Elicitation discussion

Day 6 in the second Elicitation discussion

Day 6 at the beginning and end of Activity II-D1,

Day 8 at the beginning of Activity II-D3

Day 8 in the groups' Candidate Ideas document

In addition, individual students were asked to formally declare models of magnetic materials on three occasions:

Day 1 at the beginning of the first Elicitation discussion

Day 6 before the second Elicitation discussion

Between days 7 and 8 in a homework assignment.

Diagrams from these occasions were combined with volunteered information from daily journals, interviews, videotapes, and group comments on computer documents, notably Activities I-D2 and I-D3.

The main tasks in this analysis were to create model categories which reasonably represented the different models used by groups, and to sort the different models into these categories. Of course, this was an iterative process in the style of a "typological analysis"

(LeCompte & Preissle, 1993, p. 257.) First an initial set of categories was created. Subsequent attempts to fit most of the models into these categories revealed shortcomings in the scheme, so modifications of the categories were made as needed. Additional data generally required rethinking category definitions. A final set of categories was developed, which is detailed in Chapter 4. Each model made by a group was fit into the categories, or "model types."

Changes in the group models were made evident by counting the model types drawn by groups at various points in the two cycles. Not too surprisingly, the changes seemed related to the experimental results that students encountered over time. Students expressed reasons for changes in their computer documents, in their daily journals, and in interviews. The changes, progression of models, and connections to experimental results are also detailed in Chapter 4.

Research Question 2: Analysis of interactions

The major source of data on student interactions was the videotapes of the small groups at work. Interview data and other videotapes also contributed. The two different analyses, of patterns of action while constructing group responses, and of normative influences in the classroom, were done using the same pieces of video. The ways these analyses were done will be described below.

Categorizing patterns in group construction of responses

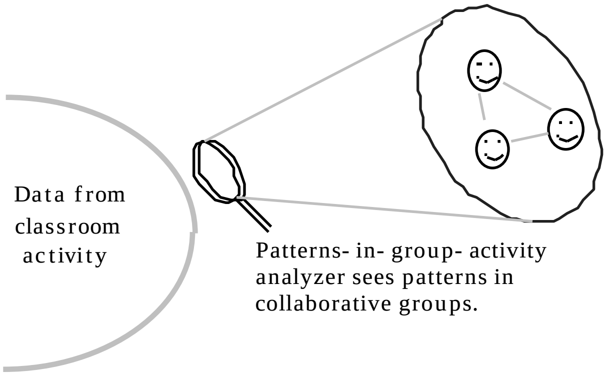


Figure 3-18: Unit of analysis for patterns in group activity

A distributed view of cognition begins by seeing cognition as an emergent property of distributed systems. Taking this view with a group of students working together, the distributed system in this case was the group of students plus the computer and their experimental apparatus. Research question 2a can be restated in these terms as "What was the cognitive system doing?" Answering this first question, which was a goal of the analysis, is a prerequisite to answering questions on how the cognitive system did what it did. Thus, this analysis of group activity types.

When groups constructed a response either on the computer screen or on a whiteboard, they usually first talked about what they would put down. After reaching agreement on something to write, they would begin creating the response, that is, typing, drawing, or writing. In the following analysis, all of these phases of the groups' activity were considered part of "constructing a group representation," not just the final phase of physically typing or drawing, because the group members were working on a response the whole time. Those extensive discussions sometimes led to model development, which was of interest in this research.

The first step of this analysis was to identify response construction episodes. In the case of work at the computer, these were defined as beginning immediately after some indication that the group had moved to consideration of a question or request. For example, a student might read a question aloud and then ask "Okay, what *do* we think?" Each "response construction" episode normally continued until the group finished typing or drawing and moved on to the next step in the document. Interruptions on a few occasions were not counted as part of the representation construction episodes.

The next step in the analysis involved constructing a set of categories of student activities that answered the question "what are the students doing now, with respect to their ideas and group model?" This analysis originated in an earlier analysis that suggested the importance of understanding what students were doing when constructing responses. Their work (usually at a computer) was varied and productive and I wanted a way to talk about it, but could not find appropriate words. It seemed that an important first step was to simply find ways to describe the various kinds of activity that the students engaged in.

Constructing this set of categories, called "activity types," required reexamining and reformulating a working set of activity types, again in an iterative cycle. The goal of this category creation and development process was to be able to characterize each moment of a response construction episode. Terminology is represented below. Within each response construction episode shown below, there are a number of events. Each event is categorized as belonging to one or two activity types.

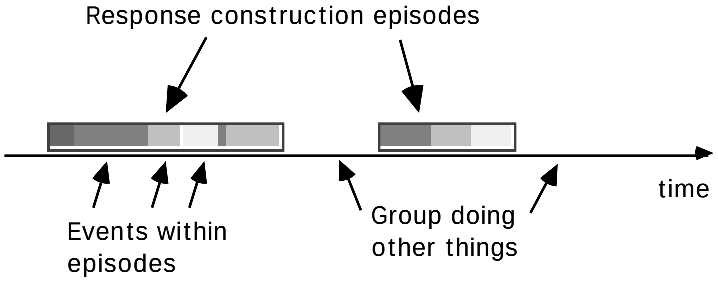


Figure 3-19: Timeline and event coding terminology

Coded events were subject to the criterion that some interaction be represented in each event. That is, each event had to bracket more than one person speaking or gesturing. This was suggested by a theoretical perspective offered by Sprod (1997) who found that it was difficult and maybe impossible to uniquely categorize individual utterances in group discussions. He suggested that people usually make statements to satisfy a number of purposes at once. Thus it is not always meaningful to analyze small parts of discussions. According to Sprod, "longer" events are more appropriate to analyze, because with them one can use the context constructed by the participants to make sense of processes. Thus, for this research, the smallest coded events were about ten seconds long, and events typically were about a half minute to a minute long. The longest single events were about five minutes long.

The names and definitions of activity types were refined and adjusted with additional viewing of video from the group. They were subjected to the requirement that every moment of the response construction episodes could be characterized by at least one type of activity. However, more than one activity type could apply to a single event, because the activity types were not mutually exclusive, and because students sometimes do more than one thing at a time. This is also consistent with Sprod's work. When events seemed to involve more than one activity type, both were coded for the event.

Once a set of activity types was generated, they were grouped into superordinate categories or "major activity types." These major activity types represent either kinds of school talk or science talk (Holthuis, 1998; Lemke, 1990).

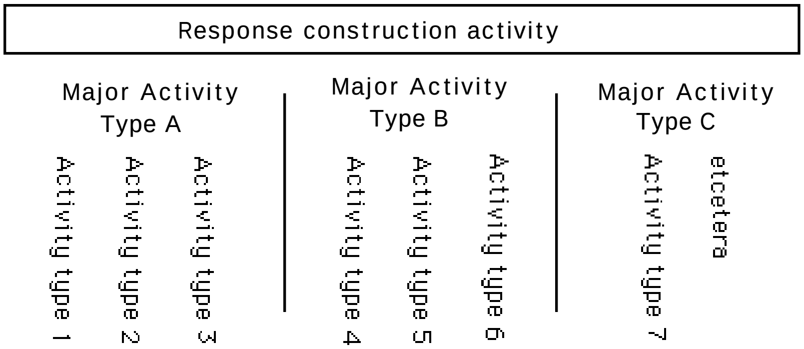


Figure 3-20: Activity types terminology

The activity types, the major activity types, and their implications are detailed in Chapter 5.

Researching norms in a physics classroom

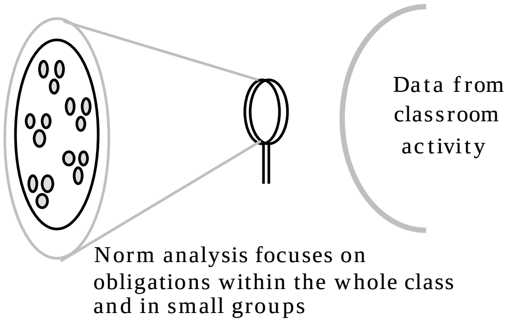


Figure 3-21: Units of analysis for classroom norms

Norm based perspectives take a broad view of group interactions

The norms observed by Yackel and Cobb (1992) developed in a class of elementary students. Each norm developed in whole class discussions and was identified in a number of children's responses. Because they are constituted interactively, one would expect norms to develop gradually, and they might be relatively easily seen in groups about the size of a school class. An analysis of norms requires a broad view of the situation.

Norms represent patterns of obligation and expectation with which each member of a group is somehow involved. Thus, norms represent properties of the interaction of the whole group. The unit of analysis when studying norms is the "whole group" that is interacting. In this research, there were two sizes of groups - the whole class, and small groups. The interactions were somewhat different in each group, so this analysis studied norms in two sizes of groups.

Relation between group interaction and whole class interactions

The whole class discussions and small group discussions represented two distinctly different settings for interaction between students in the classroom. In small group discussions, group members spoke much of the time only to each other. They tended to speak casually. In whole class discussions, on the other hand, each student was expected to speak so that the entire class could hear. These discussions were somewhat more formal. One would guess that some norms were necessarily different in the two settings. To take these differences into account, this research distinguished norms in the small group discussions and in the whole class discussions because they were separate settings.

In each setting, norms can be considered some of the "collective products" of the group interaction (Hatano, 1996). Other parts of the collective product can be ways of acting, special language, particular statements or claims, and even physical representations such as diagrams on the chalkboard. Hatano represents the influence of a class collective product using a diagram like the one below. Each student contributes something to the class collective product, which also influences each student. The teacher, an important influence, is not shown in this diagram, but influences and is influenced by both the collective product as well as individual students.

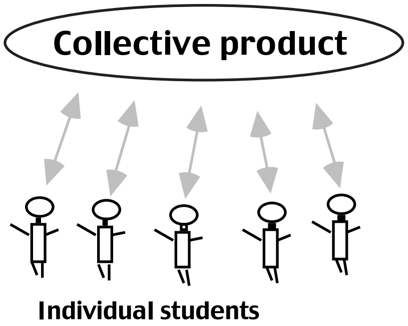


Figure 3-22: Students and the class collective product

The class studied in this research had two distinct arenas of interaction. The collective products in the whole class discussion were separate from the collective products in each group discussion. The relationships between students, groups, and two kinds of collective products are suggested below. This diagram can explain how the discussions within small groups were influenced by previous discussions in the whole class, and similarly, how whole class discussions were influenced by previous small group discussions. The students produced both collectives at different times.

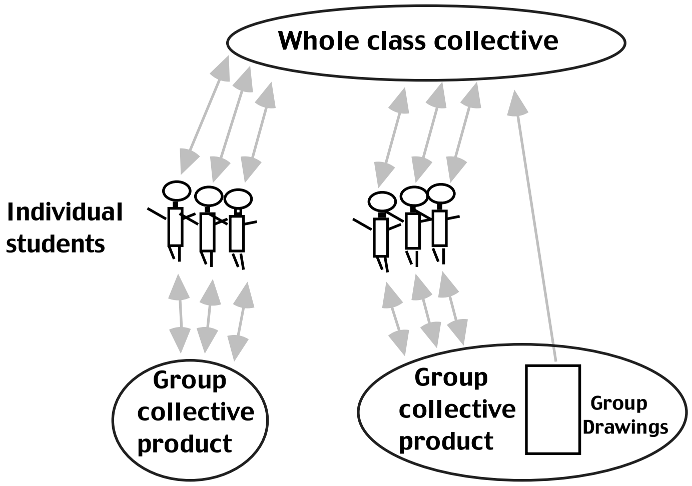


Figure 3-23: Relation of small group to whole class interaction

This diagram shows individual students as intermediaries between small group and whole class collective products. That is, the interactions within each small group may have been influenced by norms that originated in the whole class discussions. The individual students brought their own interpretations of the whole class discussions to their small group discussions. The group collective products in turn influenced what individual students said and how they said it in whole class discussions. The assumption required here is that group collective products did not directly influence the whole class interactions, but individuals could take part in whole class interactions. However, one kind of group products, the diagrams on whiteboards, contributed to the whole class, and thus became part of the whole class collective products. Students sometimes drew on their own papers diagrams that they saw on boards at the front of the room. This exception is indicated in the diagram above.

Because of this complication, this research differentiated whole class norms from small group norms. For analysis purposes, norms found in one arena could be valid without being evident in the other arena.

Implications of interactive constitution

Classroom norms arise out of the interaction between people (and between people and other structural aspects of the environment.) Therefore it is possible that different norms could arise in different classrooms because they had different students and teacher, and in fact a teacher with a number of classes could encounter different norms in different classes. Also, because norms emerge in interactive constitution, the particular history of each classroom influences the development of particular norms. The action of a student or teacher in a particular situation may have effects later on, when other individuals partly take that prior action into account in their own action. Thus, detailed descriptions of classroom norms may be unique to the classrooms in which they arise.

One would think , however, that there might be some similar norms in different classes. If a teacher emphasizes the use of evidence in explanations, for instance, and students respond in turn, then over time the class might constitute a norm about use of evidence in explanations similar to norms in other classes in which evidence is emphasized. If the course materials promote the expectation that students will have to explain their reasoning, then similar norms about explanations might arise in most courses that use these materials. Therefore the particular norms identified in this study, despite their idiosyncracies, should resemble norms that arise in other courses using similar instructional strategies.

Differences due to physics discipline and course structure

Cobb and Yackel considered norms within a second grade mathematics classroom. Their sociomathematical norms all involved criteria or standards for students' explanations of their solutions to mathematical problems. Cobb and Yackel reported no sociomathematical norms about other kinds of mathematical issues. However, physics inquiry often differs from mathematical inquiry by relying more heavily on experimental evidence. In physics, experimental results are subject to interpretation, and may not be easily accepted as "proving" or "supporting" any particular idea. Because of this, one might expect classroom sociophysics norms to address relations between experiment and explanation as well as (possibly) the quality of students' explanations.

Also, because much of the students' time was spent in small groups, the majority of the video data showed only two groups. Thus while previous research identified norms that applied to the whole class, this research focused mostly on norms as they were constituted in small group work. This does not imply that the norms which were identified were characteristic only of the small group studied, only that they were observed primarily in small group interaction.

Identifying classroom norms

Cobb and Yackel's norm framework provides researchers with a way to organize inferences about obligations and expectations in a classroom, and it arises from a theoretical perspective that accommodates both interactions and cognition. Because the framework seemed fruitful, this research appropriated it with modifications appropriate to a physics course. The overall framework, shown below, is included to provide initial definitions of sociophysics norms, and classroom physics practices and models.

Table 3-2: Slightly modified interpretive framework

Social Perspective	**Psychological Perspective**
Classroom social norms	Beliefs about one's classroom role, others' roles, and the general nature of school activity
Sociophysics norms	Beliefs about the nature of scientific knowledge, how one learns science, and scientific values
Classroom physics practices and models	Physics conceptions and understanding of scientific inquiry

Besides replacing "mathematics" with "physics," the main difference from Cobb and Yackel's framework is that the classroom has physics models as well as practices. In the math class, the term "practices" emphasized how students approached math problems. In this physics class, models were shared, talked about, and developed. Certain models of magnetic materials, or certain model features, became common among many groups, and perhaps "normative."

The above modified framework is connected to this research in the following ways: from the left side of the table, classroom sociophysics norms are the topic of this section and are a major part of Chapter 5. Features from the bottom row, classroom physics practices and models, and some individual physics conceptions, are analyzed in Chapter 4. That analysis does not distinguish social and psychological perspectives. Students' beliefs, represented on the right side of the table, were not analyzed in any detail but they undoubtedly played parts in the development of classroom norms.

Because of the physics topic, and the inquiry nature of the classroom, particular issues were of interest. As mentioned before, students' reasons for making statements about magnetism, and ultimately their use of experimental evidence seemed important to the intended learning in this course. Thus, this research focused on norms involving evidence and models.

However, the actual norms in the classroom could not be anticipated. It was important to identify candidate norms that represented obligations and expectations that were apparent to an unpracticed eye in the video data. An initial typological analysis contributed a list of possible norms. This exploratory survey, based on the video data in one group, uncovered many types of possible norms. This analysis was a search for all types of norms in the group discussion as well as in the whole class.

The actual norms reported in Chapter 5, however, are the result of a reduction and polishing process involving analytic induction. Some potential norms generated in the initial analysis were selected for further study based on their apparent relevance to model development. Examples are norms involving supporting claims or using experimental results. When the group members seemed to be negotiating or otherwise constituting an obligation or expectation relating to claims, these events were collected as evidence for a norm about claims. Similar events were compared with the original description of the norm that appeared to be operating in that situation, and modifications were made to the description as necessary. Counterexamples were sought, and when found, an explanation had to be formulated, or the description of the norm had to be modified. This process was repeated as more and more video data was reviewed.

Because the Static Electricity and Magnetism unit was taught early in the course, students' expectations were likely to change from the first Elicitation to the end of the second Cycle. The first day of data collection (Day 1 above) was actually the second day of the course. The nature of students' interaction in the course had changed by the fifth week of the course when groups worked through the Cycle II Application. Thus, some norms emerged later in the data collection period. While they are described in a static way in Chapter 5, they did not exist at the beginning of the course, and they changed somewhat as time went on. The purpose of the analysis of norms was primarily to identify norms and their connection with groups' model development, rather than to detail changes and developments in the norms themselves.