Development of Knowledge about Electricity and Magnetism during a Visit to a Science Museum and Related Post-Visit Activities

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ABSTRACT: This article reports on part of a larger study of how 11- and 12-year-old students construct knowledge about electricity and magnetism by drawing on aspects of their experiences during the course of a school visit to an interactive science museum and subsequent classroom activities linked to the science museum exhibits. The significance of this study is that it focuses on an aspect of school visits to informal learning centers that has been neglected by researchers in the past, namely the influence of post-visit activities in the classroom on subsequent learning and knowledge construction. This study provides evidence that the integrated series of post-visit activities resulted in students constructing and reconstructing their personal knowledge of science concepts and principles represented in the science museum exhibits, sometimes toward the accepted scientific understanding and sometimes in different and surprising ways. A descriptive interpretive approach was adopted, with principal data sources comprising student-generated concept maps and semistructured interviews at three stages of the study. Findings demonstrate the interrelationships between learning that occurs at school, home, and in informal learning settings. The study also underscores for classroom teachers and staff of science museums and similar centers the importance of planning pre- and post-visit activities. The importance of this planning is not only to support the development of scientific conceptions, but also to detect and respond to alternative conceptions that may be produced or strengthened

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INTRODUCTION

This article reports part of a larger study of how 11- and 12-year-old students construct knowledge about electricity and magnetism by drawing on aspects of their experiences during the course of a school visit to an interactive science museum (the Sciencentre, Brisbane, Australia) and subsequent classroom activities linked to Sciencentre exhibits. The larger study contains 12 case studies, of which two are reported here. The present work has the following objectives:

1. To describe the experiences of two Year 7 students, Roger and Heidi, during their Sciencentre visit and subsequent participation in classroom activities.
2. To report on our understandings of the construction of Roger and Heidi's knowledge about the nature of electricity and magnetism.
3. To reflect on some of the implications of these case studies for classroom teachers, students, museum educators, and the science education community at large.

SIGNIFICANCE

A substantial volume of research has been reported concerning children's learning experiences during visits to informal learning centers such as science museums, field study centers, and similar locations (Ramey-Gassert, Walberg, & Walbert, 1994; Rennie & McClafferty, 1996). As a result, much is known about the effect of different kinds of exhibits on visitors (Cone & Kendall, 1978; Peart, 1984; Wright, 1980), effective gallery design, and behavior of visitors (Anderson, Hilke, Kramer, Abrams, & Dierking, 1997; Borun, Chambers & Cleghorn, 1996; Burnett, Lucas, & Dooley, 1996; Falk, Koran, Dierking, & Dreblow, 1985; Sandifer, 1997), the distraction to learning caused by the novelty of the environment (Falk & Balling 1982; Falk, Martin, & Balling, 1978; Lubow, Rifkin, & Alek, 1976; Martin, Falk, & Balling, 1981), and pre-visit strategies for enhancing learning during school-organized class visits (Anderson & Lucas, 1997; Gennaro, 1981; Kubota & Olstad, 1991; Orion & Hofstein, 1994).

By their very nature, visits to informal learning centers often result in the students experiencing many phenomena and ideas that are new to them. These experiences occur in light of the context in which the individual is situated and ultimately have a strong influence on the ways in which knowledge is constructed. Therefore, one might expect that science teachers cognizant of contemporary constructivist theories of learning would be eager to explore and exploit these new experiences to guide their students' developing understanding of science through the visit to informal learning centers followed by appropriate post-visit activities. The reality is that teachers seldom implement post-visit activities specifically designed to do so (Bitgood, 1989).

Failure to follow-up visits to informal learning centers is of concern, not only because of missed opportunities to support newly learned scientific concepts, but also because of the likelihood of the visit giving rise to, and sometimes reinforcing, unexpected and potentially inhibiting alternative conceptions in many students. The significance of this study is that it focuses on an aspect of school visits to informal learning centers such as a science museum that has been neglected by researchers in the past, namely the influence of post-visit activities in the classroom on subsequent learning and knowledge construction. Teachers and informal learning center staff value the positive contributions to students' learning in the affective domain that stems from visits to informal learning centers, and we acknowledge and value such learning. However, many teachers also anticipate gains in cognitive learning about topics that are included in their schools' science program, and schedule class visits to informal learning centers accordingly. The focus of this study is students' cognitive processes and learning outcomes associated with such visits.

METHODOLOGY

A descriptive interpretive approach was adopted in the study consistent with our belief that knowledge is socially constructed in ways that are idiosyncratic, progressive, integrative, dependent on prior knowledge, and not entirely predictable. Furthermore, the research objectives required a series of cycles of data gathering, analysis, and interpretation, each informing and shaping the next. This approach, which has become known as a hermeneutic cycle (Guba & Lincoln, 1989), is characterized by the repeated feedback of researcher perceptions to the participants for the purposes of checking, elaborating, and modifying at key stages in the progress of the research. While the entire class was involved in the pre- and post-visit activities and the visit to the Sciencentre, 12 students were selected for more intensive study. These students were interviewed at three stages of the research — prior to their museum experiences, after their museum experiences, and after their participation in subsequent post-visit activities. In addition, eight were fitted with radio microphones during the visit and the post-visit activities for the purposes of recording their conversations while interacting within the gallery and during the post-visit activities.

An extensive data set was compiled including concept maps completed by all students at the three different stages in the research (pre-visit, post-visit, and post-activity), video recordings of the Sciencentre visit and the post-visit activities, student worksheets, audio recordings of interviews conducted with 12 selected students on three separate occasions, audio recordings of these same students' conversations during their visit to the electricity and magnetism gallery in the Sciencentre and subsequent post-visit activities, and our own field notes. Full transcripts were made of all interview tapes and of relevant sections of the students' conversations during the visit. Roger and Heidi, the subjects of the present report, were two of the 12 specially selected students.

PROCEDURE

Participants in the study were 28 students (15 girls, 13 boys) in Year 7 at a state primary school in Brisbane, Australia. The school was situated in a relatively affluent suburb, and was well resourced. The teacher was a young man who, in our opinion, was somewhat more interested in, and knowledgeable about, science than most of his colleagues in the school. Prominent in the classroom were numerous computers, posters, and other evidence of students' work in various subjects displayed on walls or suspended from the ceiling. There was a range of simple apparatus to support the teaching of topics included in the primary science syllabus. One of us (D.A.) planned and directed all of the activities associated with this study, liaising closely with the teacher and Sciencentre staff to coordinate students' experiences at both sites. There were three phases of the study: pre-visit, during which students' prior knowledge about electricity and magnetism was probed and investigated; Sciencentre visit, including pre-visit orientation, actual visit, and a brief follow-up session; and post-visit, involving in-class completion of several practical activities explicitly linked to specific Sciencentre exhibits. Students' knowledge about electricity and magnetism was also investigated at the conclusion of the second and third phases, with particular attention being paid to noting changes that occurred in each phase.

Pre-Visit

An important part of the pre-visit phase was to teach students to draw concept maps in the manner suggested by Gunstone and White (1992). A training session was conducted for this purpose, in which students were shown and given the opportunity to discuss several simple concept maps (which were referred to as "mind maps"). They then worked together in pairs to produce their own maps of food webs, a topic with which they were quite familiar. Subsequently, they constructed individual concept maps about electricity and magnetism. The students were provided with numerous small pieces of paper on which to write concepts to be included and large sheets of paper on which to arrange the configuration of their respective concept maps. When they were satisfied with the number and placement of these concept labels, students pasted them to the large sheet of paper and added connecting arrows and linking statements in the usual fashion. Following careful examination of these maps and discussions with the teacher, we selected the 12 students for more intensive study. These students were selected partly because their concept maps provided us with a range of structure (few links or many links between concept nodes), scientific conceptions, and alternative conceptions. Other selection criteria included the teacher's recommendation that the students were able and would be prepared to communicate effectively with us, and our desire to ensure roughly equal representation of girls and boys. Four to five days after they drew their first concept maps about electricity and magnetism, these 12 students were interviewed individually for approximately 25 minutes about their knowledge of electricity and magnetism. The concept maps provided a focus for the interviews and opportunities were given for the students to elaborate details of the maps and to add new or modify concepts and/or linkages as they saw fit.

Sciencentre Visit

Consistent with advice provided by several researchers (Anderson & Lucas, 1997; Kubota & Olstad, 1991; Orion & Hofstein, 1994), students were prepared for the Sciencentre visit on the day preceding the visit by means of a 30-minute presentation that included color slides of the Sciencentre layout, the schedule of activities for the visit, the types of exhibits to be encountered, and the fact that some would be specially identified as exhibits that all students were asked to visit. These exhibits were *electric motor; generating electricity; electricity from a magnet; hand battery; Curie point*; and *making a magnet*. Students were advised that the particular gallery that housed the electricity and magnetism exhibits would be under video surveillance and that several research assistants would be observing students in that gallery. They were not shown slides or given any information about specific exhibits.

In terms of McManus's (1992) description of science museum types, the Sciencentre would be classified as a "third-generation museum" (p. 164), which presents ideas instead of objects in a decontextualized scattering of interactive exhibits, which can be thought of as exploring stations of ideas. During the Sciencentre visit, students spent about 40 minutes in galleries featuring exhibits related to sound and mechanics before entering the electricity and magnetism gallery. They spent about 30 minutes in the latter gallery, which also included exhibits related to light and color. Students were permitted to engage and interact freely with the exhibit elements and each other in the social context. Most exhibits, including the electricity and magnetism units, were stand-alone, hands-on, and phenomenon-based, with little context or no contextual links to real-world application of the scientific principles that they attempted to demonstrate. The visit concluded with a 30-minute presentation to the entire class by Sciencentre staff. The presentation ranged over the phenomena represented by exhibits in the center and included some general references to electricity and magnetism. The day after the Sciencentre visit, students completed a second concept map about electricity and magnetism, following the same procedure as described for the pre-visit. Each of the 12 students was interviewed for approximately 25 minutes, two or three days after constructing these concept maps, and allowed to modify and add to their concept maps during the interview.

Post-Visit

One week following the Sciencentre visit, students participated in two sessions of post-visit activities. The first involved students working in pairs to select two of the six target exhibits that they found interesting, to describe their own involvement with these exhibits, and to provide an explanation of how they believed the exhibits worked. This activity aimed to have students review their Sciencentre visit and to stimulate possible construction and reconstruction of their understanding of the concepts and principles involved in the exhibits. The second activity engaged students in open-ended practical experiments, which had obvious similarities to two of the Sciencentre exhibits. One involved moving a magnet near a coil of copper wire attached to a microammeter, to produce a small amount of electrical current. The other consisted of making an electromagnet by passing a direct electric current through the solenoid containing a soft iron bar. The presence of the resulting magnetic field was demonstrated by the *ability* of the iron core to attract metal paper clips. Students experimented with both sets of apparatus, and other materials conveniently at hand, such as paper clips, pencils, and erasers.

Students constructed their third and final concept maps on the day after the post-visit activities. Each of the 12 selected students was interviewed for the last time 1–4 days after completing the concept maps. During these interviews, they were asked to reflect on the entire experience and what they had learned about electricity and magnetism. All three of their respective concept maps were referred to at appropriate times in the interview and they were asked to comment on differences that they recognized. As was the case on the earlier occasions, students were encouraged to modify or extend their third concept map during the interview. Such modification was made in different colored inks to enable us to detect transformation in students' knowledge.

All concept maps (pre-visit, post-visit, and post-activity) were redrawn using the *Inspiration* software package. Oval-shaped nodes represented students' original drawings, rectangles with rounded corners represented nodes drawn by students on their maps during the course of their probing interview, and rectangular-shaped nodes were those added by the researchers after analysis of the interview data sets. In order to improve the readability of the maps, rectangular nodes with a shaded left side represent repeated nodes on the diagram to which interconnection should be directed. Furthermore, only new transformations, not previously shown on earlier maps, were detailed in the form of rectangular node on subsequent maps. On occasions where the researchers felt the interconnections between nodes were weak or uncertain, links were denoted by a dashed line.

DATA ANALYSIS

A combination of semistructured interviews and concept maps was an effective means to document and interpret students' cognitive knowledge at the three phases of the study. The student-generated concept maps and photographs of exhibits were employed as aids in the probing interviews to reveal and interpret students' knowledge states during the various phases of the study. A pilot study had demonstrated that these methods were powerful and effective, stimulating students to reflect on their own knowledge and understandings, and making the interview process both fruitful and productive in revealing and interpreting students' knowledge.

Students were questioned about their reasoning and rationale for links between various nodes on their concept maps, as well as the experiential events, which they perceived were important in the development of their knowledge. At the conclusion of each interview, students were encouraged to make any additions or changes to their concept maps that they felt they would like to make. The additions were usually in the form of additional links and concept nodes, and, on a few occasions, changes to the nature of the propositional links between nodes.

The data sets were analyzed progressively, so that all of the pre-visit phase data for all 12 students were analyzed prior to the post-visit and post-activity phase data. This facilitated the formation of a coherent view of students' understandings at each phase, unbiased by interpretations made in other phases. Detailed analysis of the data sets involved several steps: careful scrutiny of the student-generated concept maps and transcripts of related interviews; compilation of a list of concepts held by each student as evidenced by the concept maps and interview; interpretation of students' knowledge, understanding, and related prior experiences; and compilation of concept profile inventories (CPIs) (Erickson, 1980; Taylor, 1997) for each of the 12 selected students.

For the most part, students' own words were used to describe their own concepts and understandings recorded in the CPIs. Analysis proceeded in similar fashion for the post-visit and post-activity phases of the study, producing a total of 36 inventories—three for each student. The CPIs for each student were analyzed for ways in which the student's knowledge was transformed across the three phases of the study. In order to reduce the complexity of the representations and more clearly identify changes in student knowledge and understanding, post-visit and post-activity CPIs contained only those sets of knowledge and understandings that were deemed to be in any way different from those of the prior phases of the study. In addition to the CPI data sets, a supplementary data set, called the Related Learning Experience (RLE), was identified for each student, and, where possible, linked with identified concepts in the students' CPIs.

During the course of the interviews, students were asked how they came to "know" an idea or concept they had written on their map or articulated during the course of the interview. For example, if a student held the concept *magnets attract*, the student was asked how he or she came to know this piece of knowledge by describing related personal experiences. The pilot study had demonstrated that, in some instances, students were not able to articulate the origins of their understandings and, to this end, only RLEs that could be connected to a concept in the CPI for each student were reported. Comparisons of individual student data sets between phases resulted in partial accounts of the processes by which knowledge was constructed. These data helped both the interpretation and description of the ways in which students' knowledge was transformed across the three phases of the study.

FINDINGS

Case reports for each student were compiled. Both Roger and Heidi constructed knowledge about magnetism and electricity as a result of their Sciencentre and classroom-based post-visit activity experiences. In some instances the knowledge constructed was consistent with canonical science, and, in other instances, it comprised alternative conceptions, as revealed in the following case studies. That this occurred was not the principal focus of the study. Rather, the case studies represented our interpretations of how these students constructed new knowledge and understanding about magnetism and electricity.

Roger

Roger was one of the most academically capable students interviewed during the course of the study. His understanding of the topics of electricity and magnetism probably surpassed the knowledge of many junior high school students. Evidence for this claim is supported by his initial pre-visit concept map (Fig. 1) and initial face-to-face interview, during which Roger was probed about his understandings of the topics through open-ended discussion and elaboration of the contents of his self-generated concept map. From analysis of the contents of the concept map and the interview discourse, Roger appeared to have many "correct" scientific understandings of the role of magnets in electricity production and various forms of commercial electricity production using hydro, nuclear, wind, and solar power. For example, his understandings of the properties of magnets included an awareness of the fact that magnets had two poles, denoted as north and south (a concept held by only half of the 12 students), and that magnets had the ability to attract certain metals and other magnets. He had some understanding of the properties of north and south poles of a magnet in relation to the north and south poles of Earth. However, he confessed to being uncertain about the specific nature of what these relationships entailed, because it seemed to him that the north pole of a compass should be attracted to Earth's south pole. Figure 1 details Roger's initial concept map combined with additions Roger made during the course of his initial interview (rounded-rectangle nodes) and additions made by us on the basis of the pre-visit interview (rectangle nodes). Our additions are an interpretation of what we believe the student knows, but has not indicated on his map. They are included to represent more fully the knowledge of Roger.

Understanding of Magnetism. When recalling his visit to the Sciencentre, Roger described his interaction with an exhibit that was intended to demonstrate the effect that heating of metals has on their *ability* to be attracted by magnets. The exhibit, entitled *Curie point*, consisted of a coil of wire suspended in an elevated position, to which a small bar magnet was magnetically attracted and in contact. The visitor presses a button that causes the wire to heat up to a point where it glows "red hot" and loses its magnetic properties, resulting in the magnet falling away. Many students who interacted with this exhibit, including Roger, constructed their experience at the exhibit in terms of heat being "a repelling force to magnets." When questioned about the exhibit, Roger expressed the view that heat was in some way involved with the process of magnetic attraction and repulsion, but he was not confident enough of his understanding to incorporate it into his second concept map produced after the science museum experience (Fig. 2).

The post-visit activity involving the construction of an electromagnet appears to have entrenched Roger's association of heat with magnetic attraction and repulsion. The intention of the post-visit activity was to provide students with experiences that would further aid construction and/or reconstruction of their knowledge of the relationships between electricity and magnetism in ways consistent with accepted scientific understandings. Roger noticed an additional heating effect of passing current through the solenoid, to which he referred in the subsequent post-activity (final) interview:

> A: Well, I was in the group with Stephen and Geoffrey and we did all the things that we—Geoffrey played around a little bit and made a few sparks and yeah . . . , I knew it had something to do with heat, the making of electricity, but I wasn't sure until then.
>
> Q: So what do you think heat's got to do with electricity production?
>
> A: Well, we found that when you had the iron core in it and it was—the coil of wire was electrified, it became hot and after a while the iron coil would magnetize, but if you—in

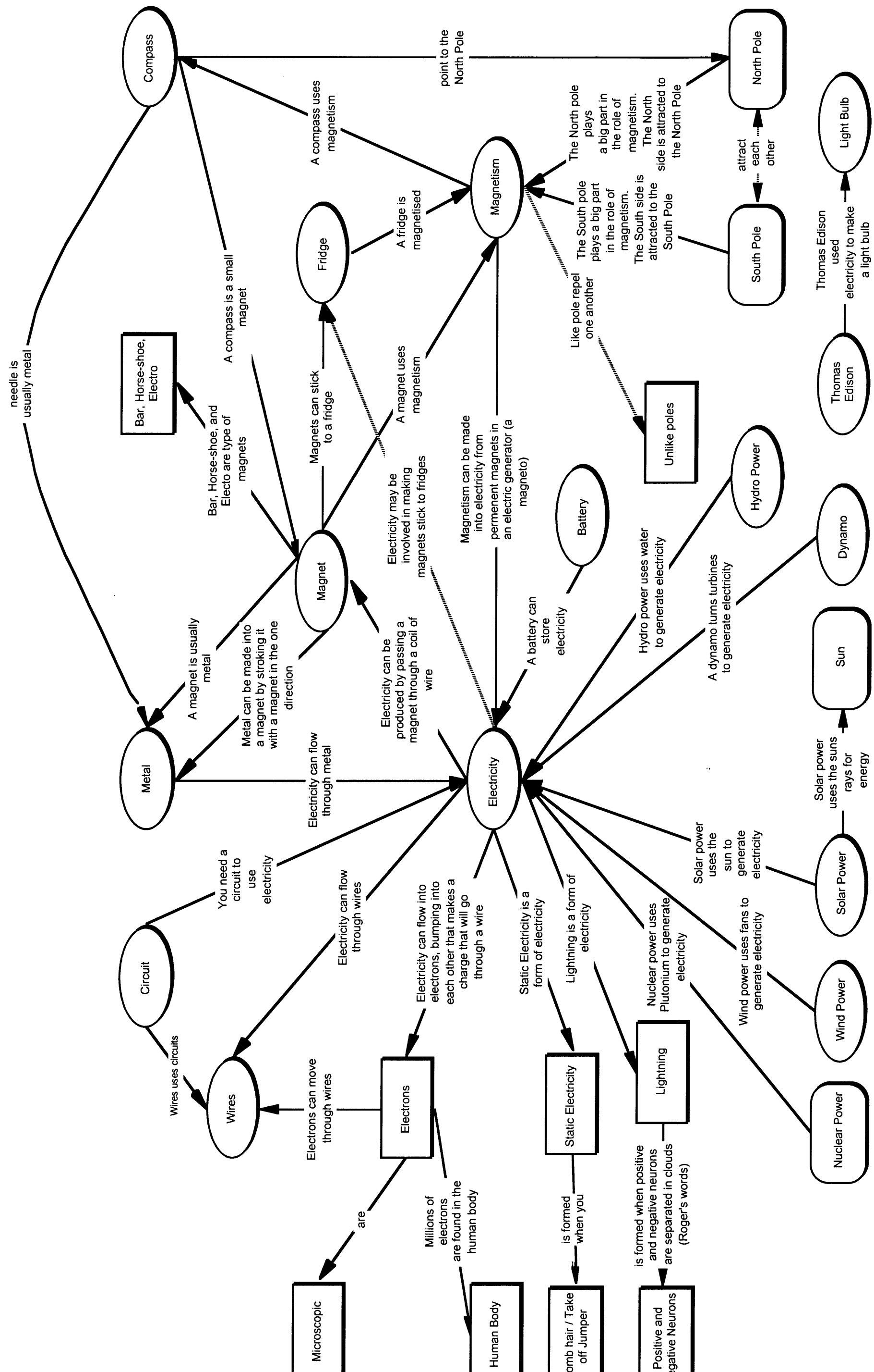

Figure 1. Roger's pre-visit concept map.

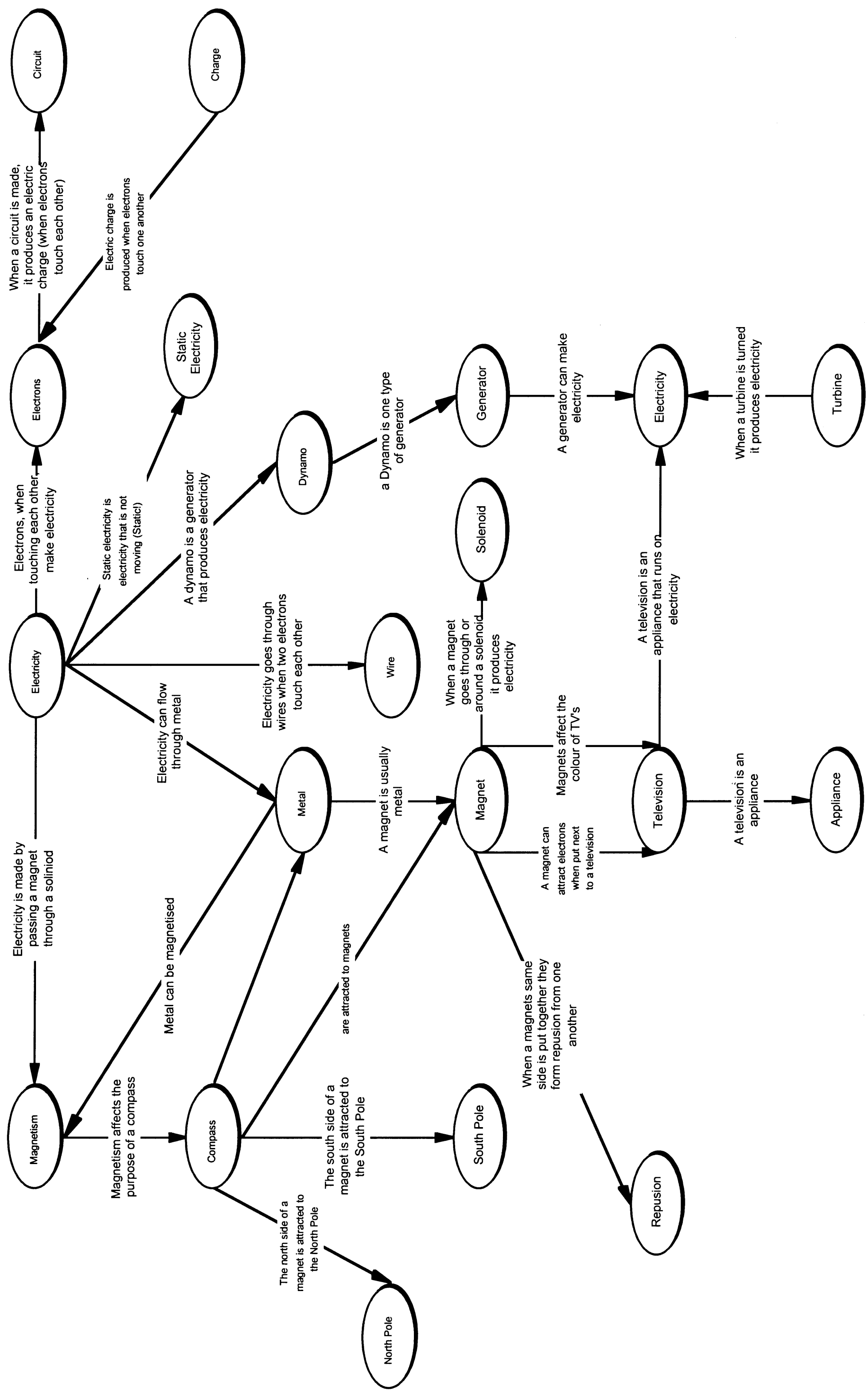

Figure 2. Roger's post-visit concept map.

ours if you took it out of it and you tried to pick up some paper clips or something, it wouldn't so you had to keep it in all the time.

Q: Do you think heat's got anything to do with the making of a magnet?

A: Yeah, that was one of the things that I wasn't sure about.

Q: Do you think that you learned anything new from doing those activities—making an electromagnet and making electricity?

A: Yeah. I found out that heat has actually got a property in making the iron core magnetized.

Later during the interview, he described an experiment undertaken with his father to test the association of heat and magnetism. Roger tested his ideas by observing the attracting forces of refrigerator magnets when the refrigerator was turned off and allowed to heat up. Roger claimed that when the refrigerator was off for a period of time the magnets ceased to attract and fell off. In his attempt to explain this phenomenon he wrestled with the complexity of four semi-independent competing notions:

1. Heat is generated at the back of refrigerator, arising from the heat sink.
2. The refrigerator will become warmer when turned off.
3. Electricity is somehow flowing through the refrigerator when it is plugged in and switched on.
4. The need for electricity and the presence of heat to activate the electromagnet in the post-visit activity experiment.

As a result of these experiences, Roger constructed knowledge that confirms for him an association between heat and magnetism. This alternative conception is surprising and alerts science educators to the possibility of unintended learning outcomes from visits to places such as the Sciencentre which may be reinforced by other experiences. The following is an excerpt from the final interview with Roger:

Q: Take a look at your Sciencentre map (Fig. 2) and the map you made before your visit to the Sciencentre (Fig. 1). What things have changed about your knowledge?

A: Was this the—yeah. Well, I didn't really bother to put into a fridge, but I later learnt that the heat has to do with the fridge's attraction to magnets. Umm, I asked my dad about it and he said that—that umm—that umm—that the fridge has the heat flowing through the umm—the metal of the fridge and that had something to do with the—with the way that the fridge was actually magnetized. And so we tried it. We turned the fridge off for a little while and stuck magnets on when it was on. And then about 30 seconds after we turned it off, they fell off.

Q: Did they really?

A: Yeah.

Q: That's amazing. The fridge magnets fell off when you turned the fridge off?

A: Yeah, but my dad was pretty amazed, too.

Q: He was amazed, too?

A: Yeah.

Q: So it's got something to do—the fact that those magnets are sticking there, does it have something to do with the temperature of the fridge, or does it have something to do with the fact that there's electricity flowing through the fridge?

A: I think it's got a mixture of both. Umm. I think. I'm not quite sure, but, umm, it's got something to do with the electricity flowing through the fridge. And the actual heat that it's producing. If you ever feel the back of the fridge or the top of the fridge, it's really hot.

Understanding of Electricity. From the analysis of Roger's concept map and face-to-face interview following the visit to the science museum, there appeared to be two main areas of knowledge construction about electricity that had occurred. First, Roger acquired a deeper and scientifically accepted understanding of the notion of *static electricity* as a result of participation in the interactive science presentation during which a member of the Sciencentre staff produced static electricity by rubbing a balloon on a volunteer's hair. Roger's concept map and following explanation contained new understanding of the processes of static electricity production and that this form of electricity is not a moving type, but stationary. Second, Roger constructed knowledge of the relationships between electrons and electricity. From reading text panels associated with a number of the electricity exhibits, and in particular, the *generating electricity* exhibit, Roger constructed alternate understandings that electricity flows when two electrons touch one another and such flow occurs within a circuit. This can be seen in the addition of such concepts in Figure 2.

In later post-visit activities, when students made an electromagnet and generated electricity by moving a bar magnet near a solenoid connected to a microammeter, Roger constructed further meaning and understanding of electricity. An additional round of concept mapping and interviewing revealed that Roger had incorporated ideas that electricity was in the form of positive and negative electrons; that electricity flows from the negative to the positive; and that a microammeter measures the flow of electricity (Fig. 3). When probed about his understanding of electricity production in terms of why the magnet was able to generate electricity in the solenoid, Roger resorted to his understanding of the attractive properties of magnets and his newly constructed knowledge about the electricity production effect of electrons touching gained from his Sciencentre experiences. Roger explained the phenomenon in terms of the magnetic field of the bar magnet attracting two electrons together within the wire of the solenoid, thus producing electricity. Further probing revealed the concept of charge. Roger asserted that the two electrons when brought together produce a charge, which then allows the flow of electricity:

Q: Tell me briefly about the one when we made electricity. What did we do?

A: Well, we put the iron core through the—well, that didn't really work for us, so we tuned it in a little bit and we stuck the magnet through the coil and that made a bit more electricity than just with the iron core in it.

Q: Mmm, 'cause you're putting the magnet right in the middle of it.

A: Yeah, and the magnet was actually going in and out. Yeah.

Q: What was the explanation for that? How did that make electricity?

A: Umm . . . well, maybe it sort of got something to do with the heat. Umm . . . well, if it—could . . . when—when the magnetic forces were going through the wire, maybe—maybe that brought on the electrons touching together, which allowed some electricity to flow through the wire.

Q: Electrons touching together? That makes electricity?

A: Umm . . .

Q: What is electricity? How's it related to electrons?

A: Electrons . . . well, to flow through wire, umm, when the electrons—if a negative

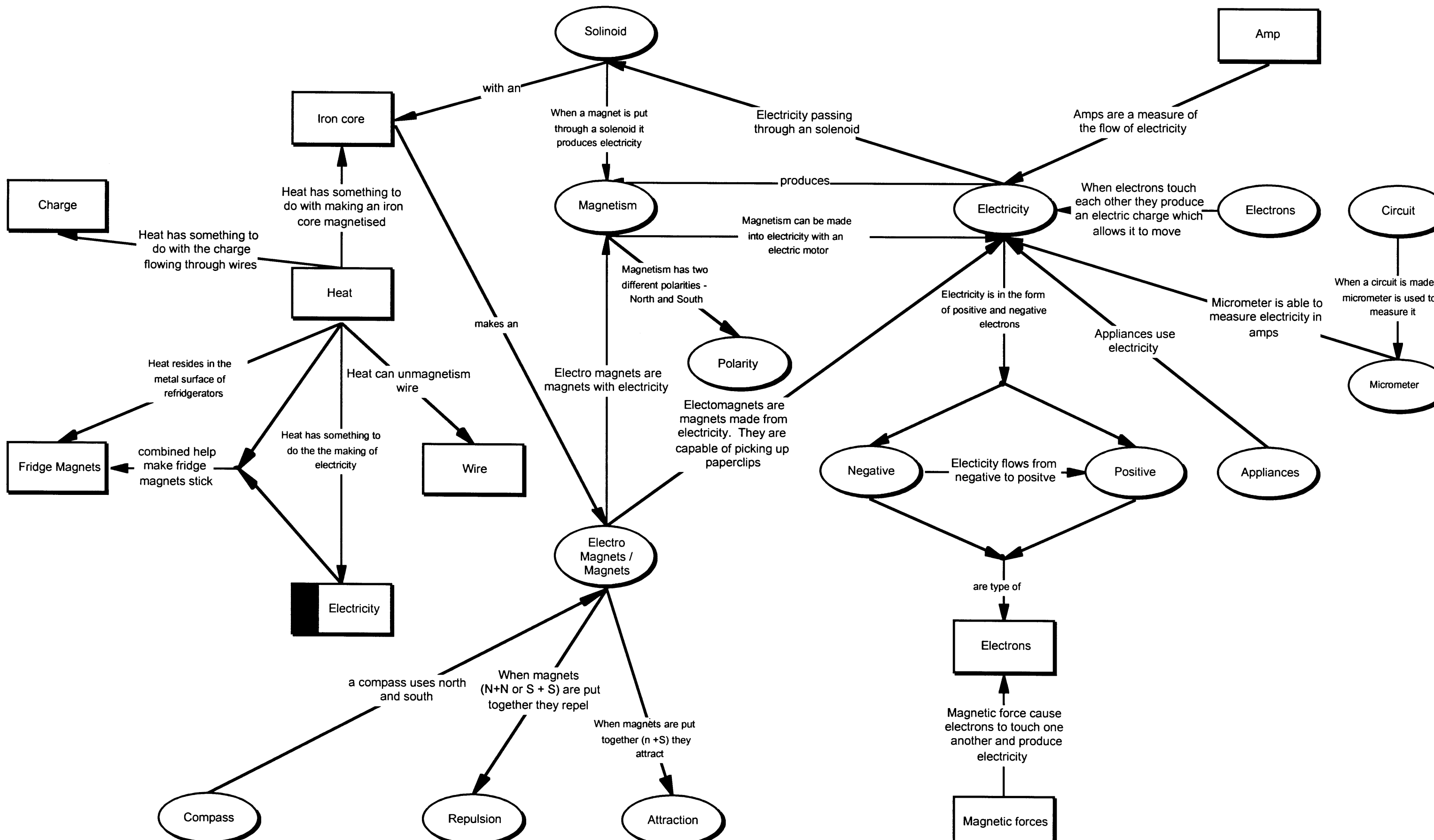

Figure 3. Roger's post-activity concept map.

> and a positive one touch, I think that's right—that—or it could be positive and positive and negative and negative—when they touch, they, umm, produce an electrical charge which then allows the electricity to flow through the wires into a light bulb or whatever.
>
> Q: And bringing the magnet in—what's going on there?
>
> A: Well, the magnet's forces would be pushing the, umm, electrons together so they produce that charge.

Understandings of the direction of the flow of electricity were constructed from Roger's appreciation that electricity flows through wire and must have an associated directional property. Roger resorted to his prior knowledge and recalled a diagram he once saw in a textbook that showed lightning moving from negatively charged clouds to positively charged trees. From this recollection, he constructed an understanding that all electricity must flow in a direction from negative to positive. Roger also constructed his understanding of the measurement of the flow of electricity in the post-visit activities through experiences on his uncle's farm, which had an electric fence. He stated that the terms "amps" and "volts" were units of electricity, and believed that amps might be a measure of the amount of flow. However, he confessed to being somewhat uncertain about these assertions:

> A: Yeah. And an amp is a measure. Like, centimeters is to a distance. Umm, and electricity can be made to a large scale, I think, with volts. I'm not sure, but my grandpa said that—see, he lives on a farm, right? And he has an electric fence to keep the cows out of his garden. And he said it's—it's 10,000 volts. Right? But the number of—the number of amps it's passing through or something like that means that when you touch it, it gives enough for it to move away from it. It's—it's at 10,000 volts, but when it's flowing it's got something to do with the amount of amps.

Figures 2 and 3 detail Roger's second and third (final) concept maps combined with additions he made during the course of his interviews and additions the researchers have included on the basis of these interviews.

In summary, some of Roger's understandings are sophisticated, insightful, and evidence of thinking at an abstract level. Other understandings are representative of surprising alternative ideas that may have been generated via his experiences at the Sciencentre and noticeable effects in the post-visit activities. It is evident that Roger's overall understandings were constructed through a series of overlapping, reinforcing experiences that were encountered in home, school, and informal contexts. Each experience appeared to have influenced the subsequent experiences and the subsequent knowledge that was constructed. Furthermore, it appears evident that Roger, in the process of wrestling with several competing ideas, was in the process of developing a cohesive personal theory of electricity and magnetism capable of explaining many of the experiences he encountered during his visit to the Sciencentre and subsequent participation in the post-visit activities.

Heidi

Heidi was described by her teacher as a sound academic achiever. Analysis of her initial concept map (Fig. 4) and interview revealed that she possessed many scientifically "correct" understandings of the topics of electricity and magnetism, in addition to some interesting alternate views. She understood that magnets could both attract and repel; attract only certain types of metals; and are an integral part of electric motors. Although she appreciated that magnets had polarity, Heidi described this in terms of "positive" and "negative" and believed that this was the same as positive and negative electrical charge.

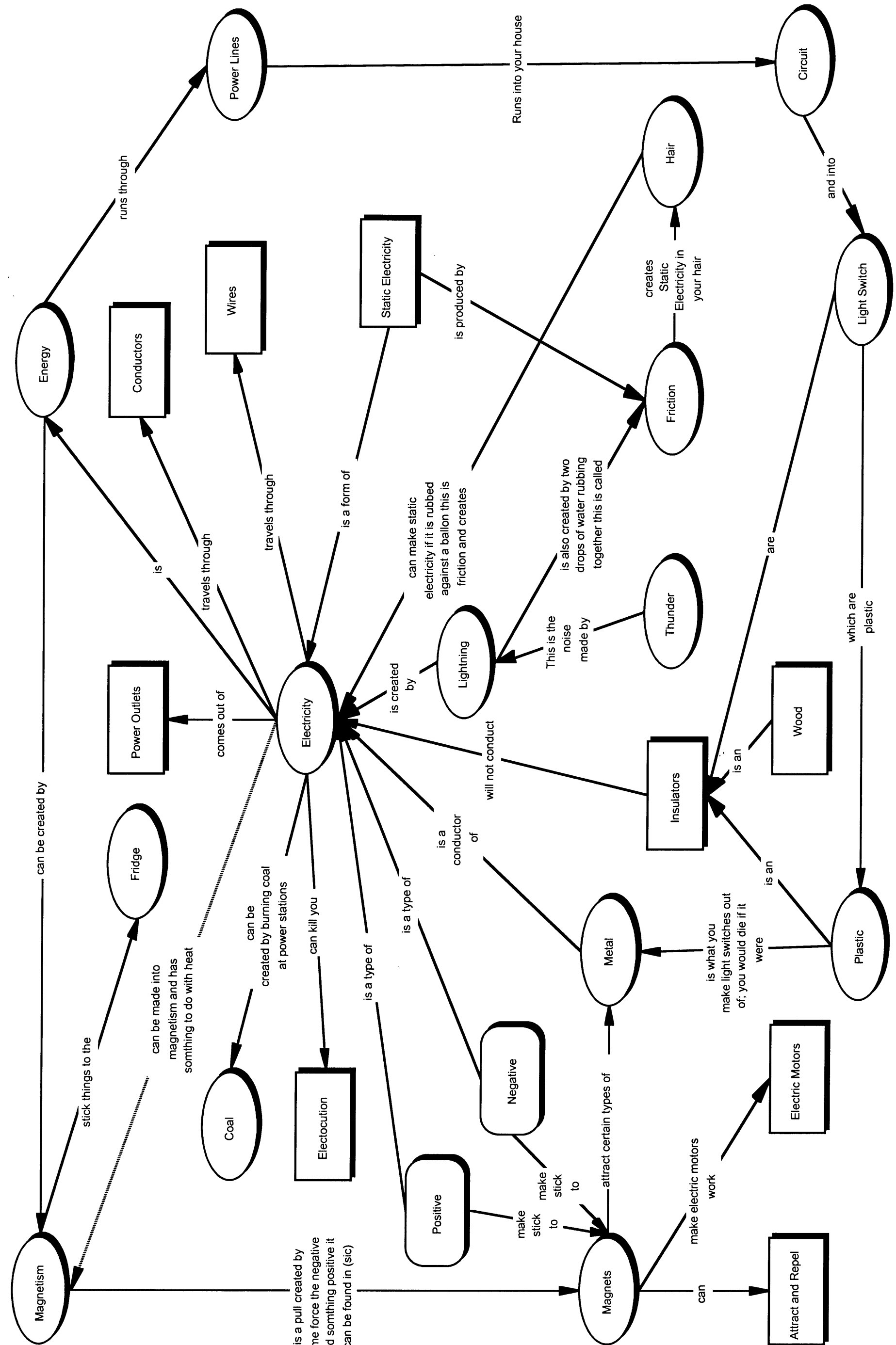

Figure 4. Heidi's pre-visit concept map.

Her understandings of electricity included an understanding of insulators and conductors; that electricity flows through wire and conductors; that electricity is produced by burning coal at power plants; that static electricity is produced by friction or rubbing things together; and lightning is a form of electricity and is produced by water droplets "rubbing together" in storm clouds. Heidi also expressed tentative and uncertain understandings about the role of electricity in generating a magnetic effect.

The association of friction with the production of electricity in the forms of lightning and static electricity later proved to be reinforced by subsequent experience and strongly influenced construction of knowledge in alternate ways. Her initial views are encapsulated by the following excerpt from her initial interview:

> Q: Tell me about what you have here on your concept map (Fig. 4).
>
> A: Okay, umm, thunder is made by lightning, and lightning is made by electricity, umm, and lightning is, umm, is created by two drops of water rubbing together and it's called friction and that creates, umm, lightning cause of the, umm, force, the negative and positive force to get the, make lightning, they jump in a bolt to the ground, umm, and friction creates static electricity in your hair, like when you run a plastic comb through your hair, that can create, umm, static electricity with sparks and stuff, umm, and, umm, hair can be made, can make static electricity if rubbed against a balloon, there's friction which then creates electricity.
>
> Q: Lightning is made by two drops of water rubbing together?
>
> A: Yep.
>
> Q: What's happening there?
>
> A: Well, in the cloud, two drops of water are just next to each other and they're just like getting rubbed against each other and that makes electrons form, so then [the] cloud is zapped on a cloud like from the bottom of the cloud to the top of another cloud, and if it, like, doesn't do that, it'll go down to the ground.
>
> Q: How'd you know that?
>
> A: TV show.

Figure 4 details Heidi's initial concept map combined with additions she made during the course of the initial interview and our additions on the basis of this pre-visit interview.

In addition to the free-choice interaction with exhibit elements that students experienced at the Sciencentre, they also participated in the live science show where a facilitator demonstrated a wide variety of scientific phenomena relating to magnetism and electricity. Among the many components of the live program were demonstrations of static electricity phenomena, including the production of static electricity using a Van der Graaff generator and by rubbing cloth over ebony and glass rods. Heidi had a number of strongly held concepts about friction and its association with electricity prior to any of the interventions introduced by the researcher.

Specifically, friction produces static electricity, and lightning is produced by water droplets rubbing together in clouds. While not directly supported by the interview or concept map data, it would be reasonable to assert that the experiences of the Sciencentre demonstration helped to reinforce Heidi's strong link between electricity production and friction.

Further evidence of the reinforcement of Heidi's "friction makes electricity" model can be seen in terms of her interactions with one of the Sciencentre in-gallery explainers. The following dialogue was recorded from a radio microphone worn by Heidi. The dialogue, recorded at the *Hand battery* exhibit between Heidi and an explainer (E), shows that the explainer provided guidance concerning the ways to interact with the exhibit. The text in italics represents the actions of both Heidi and the explainer:

> *Heidi is interacting with the Hand battery exhibit with a friend. During the course of her interactions another explainer joins in the interactions.*
>
> *The explainer provides instuctions for the current use of the exhibit.*
>
> E: Put your two center ones [your hands on the two center plates] or your two outside ones together [your hands on the two outer plates] to make a circuit . . . that's it!
>
> *Heidi follows the explainer's instructions to produce a small electric current.*
>
> E: That's more [milliamp] than I can get! Try the two middle ones . . . . See the needle [on the ammeter] goes the other way.
>
> E: Now . . . rub your hands together to get a bit of friction and then blow on your palms.
>
> E: Look at that . . . 1.5 [milliamps] just like that.
>
> H: They have this [exhibit] at the Underwater World [theme park/aquarium].
>
> *Heidi leaves the exhibit and her friend continues to interact with the exhibit.*

Interestingly, the explainer tells Heidi to "rub your hands together to get a bit of friction," before placing them on the copper and aluminum plates. The goal of this instruction was presumably to provide cleaner contact between Heidi's hands and the metal plate thus producing greater electrical current from the connection of the dissimilar metals. However, it was likely that this instruction had served to strengthen Heidi's associations with rubbing, friction, and electricity production, entrenching alternative understandings of the phenomena the exhibit was intended to portray.

Heidi engaged in a subsequent post-visit activity that aimed to develop further, and reinforce students' knowledge of, the links between the domains of electricity and magnetism, by producing a small electrical current using a moving magnetic field, a copper solenoid, and a microammeter to measure the current. Students observed the process of connecting the various pieces of equipment and the technique for replicating the generation of the small current before being permitted to conduct the experiment for themselves in groups of three or four. Following the activity, students completed a guided worksheet that required them to describe, in writing, the effects they observed and explain what they believed to be the cause of the observed effects. The following record of the dialogue between Heidi and one of the researchers encapsulates her explanation of the production of electricity:

> A: Oh well, we had to—well, the first one we had to make—create electricity with a coil, and the coil was a bit of copper wire wound around a plastic tubing. And at each end a bit of wire came off. We connected that with alligator clips to the multimeter [microammeter], and that measured the electricity. And you put the iron bolts in the middle, and you got [the] magnet and rubbed it over the top and that made—that was the magnetic field—the bar magnet we were making [a magnetic field], and when you rubbed that over the top of the coil, it creates electricity.
>
> Q: So tell me what was going on with that iron core again?

A: Well, the magnet[ic] field is rubbing against the copper wire which was creating electrons that create electricity.

Q: So the magnet actually created electrons from the wires?

A: Yeah, from the wire.

Q: Now, explain to me what is actually making the electricity. You tell me about waving this magnet in front of a coil. What is actually causing electricity to reproduce?

A: The magnetic field is rubbing against the coil and that's creating friction and that creates electricity. And the coil—it goes into the coil and goes into the multimeter [microammeter].

Q: So the magnetic field creates friction in the wire.

A: Yes.

Q: And that makes electricity.

A: Yes.

Later, during the post-activity interview, Heidi was asked about the cognitive links between her original understanding of friction and electricity and her experience with the post-visit activities.

Q: Where'd you get this idea about the two drops of water rubbing together making friction which makes electricity?

A: TV?

Q: From the TV. Was it something in class?

A: No.

Q: Because other people have mentioned that.

A: Well, it's a show that we sometimes watch in class. I was at home one day and I just watched it 'cause I was sick and it was on and that was on about it.

Q: So it the friction of these two drops rubbing together which makes electricity.

A: Yes.

Q: Now you mentioned to me in the post-visit activities that it was the friction of the magnetic force on the wire which makes electricity. Is this the same thing?

A: Yeah.

Q: Same sort of thing?

A: Yeah, and that friction and that creates electricity, and that's why that works.

It is apparent that Heidi equated the waving action of the magnet over the solenoid with the rubbing actions associated with the production of static electricity and lightning. Heidi had constructed new meaning for the effects she observed in the electricity production post-visit activity by resorting to an existing set of constructs relating to electricity production seen on a television program and subsequently reinforced by recent experiences at the live science show in the science museum. In the absence of other explanations, Heidi constructed new knowledge readily in the light of existing knowledge and had now appeared to form a coherent theory, which to her was generalizable to several situations. Figures 5 and 6 detail Heidi's understanding of these concepts she described. These maps include the additions she made during the course of the interviews and additions the researchers have included on the basis of this final interview.

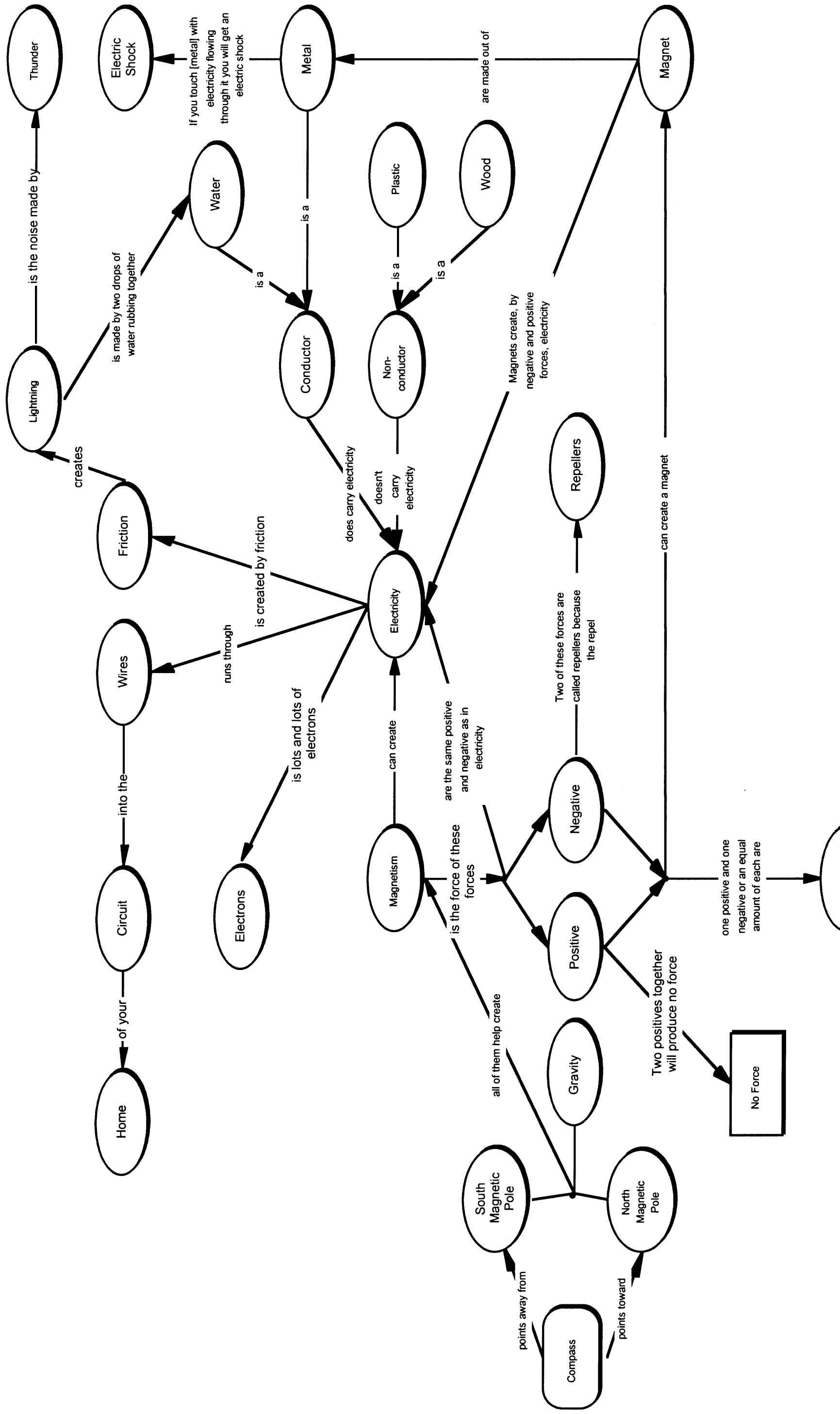

Figure 5. Heidi's post-visit concept map.

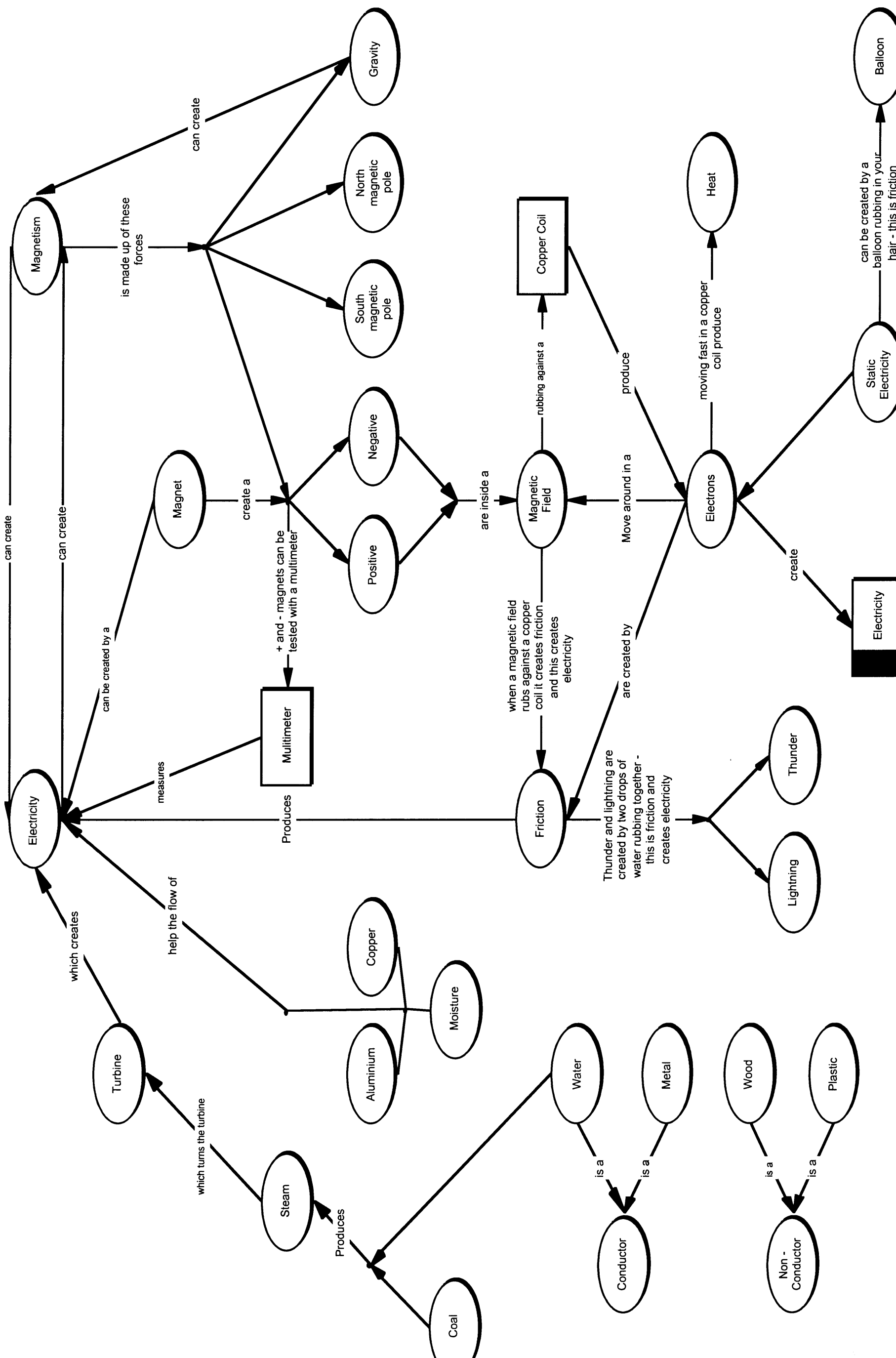

Figure 6. Heidi's post-activity concept map.

In summary, Heidi, like Roger, developed sophisticated understandings and evidence of thinking at an abstract level resulting from her Sciencentre and post-visit activity experiences. It is also clear that Heidi, in the process of seeking to provide a logical rationale to account for her experiences, developed a personal cohesive theory of electricity and magnetism to describe the production of electricity.

DISCUSSION

The series of activities in which the students in this study were engaged was somewhat unusual in that they were orientated to the physical layout of the Sciencentre, and the visit was supported subsequently by several post-visit classroom activities designed to provoke students to recall and extend their Sciencentre learning experience. Orientation to the physical layout has been recommended by various researchers (Anderson & Lucas, 1997; Gennaro, 1981; Kubota & Olstad, 1991; Orion & Hofstein, 1994); however, the effects of post-visit activities on learning from informal experiences have not been described extensively in the literature.

The study provides evidence that the integrated series of activities resulted in students constructing and reconstructing their personal knowledge of science concepts and principles represented in the Sciencentre exhibits. These constructions and reconstructions were developed sometimes toward the accepted scientific understanding and sometimes in different and surprising ways as reported.

Several key issues emerged from the case studies of Roger and Heidi. First, it is evident that both Roger and Heidi had their knowledge in the domain of electricity and magnetism transformed in many ways not specifically intended by those who planned the exhibits and/or post-visit activity experiences. From one perspective, it could be argued that some of the transformations were small and seemingly not noteworthy; for example, electricity passing through a solenoid causes heating effects, or ammeters measure electricity. These effects observed in exhibits, demonstrations, and experiments are, to the experienced facilitators, minor and not noteworthy, but they have the strong potential to lead to changes in knowledge, understanding, and personal theory building in profound ways.

In all 12 case studies under investigation in the present study, students experienced numerous small and subtle changes in their knowledge and understanding of electricity and magnetism. Many of these changes were of a form that would probably not be detected by traditional classroom-based instruments typically used by teachers to assess student knowledge. Some changes were more evident following the Sciencentre visit, where they encountered a wide diversity of science-related experiences. These findings support the fact that the students visiting science centers and similar facilities have experiences that change their knowledge and understanding in identifiable ways, as evidenced by Roger and Heidi.

It was interesting to observe that all 12 students grappled with the scientific understandings embodied in the exhibits and started to formulate tentative personal theories about electricity and magnetism phenomena. The two cases in this study developed coherent, abstract personal theories that enabled them to explain a number of phenomena. Although not in accord with canonical science, the personal theories developed by Roger and Heidi are important steps in their construction of science concepts.

Other transformations resulting from the interventions were seemingly more substantive and consistent with the intended messages of the exhibits and post-visit activity experiences: for example, better understanding the methods of producing static electricity, or magnets as an integral part of electric motors. Regardless, it appears that these transformations, whether intended or unintended, were ultimately powerful influences on the knowledge that was subsequently constructed.

Second, it seems evident that prior knowledge and experience were significant factors in the construction of an individual's knowledge. In both cases, Roger and Heidi's prior life experiences, in addition to prior experience in the science museum, demonstrated significant effects on knowledge that was constructed subsequently. In several cases, it appears that students readily constructed meaning from prior experience. Heidi's explanation of electricity production in terms of the friction effects of the magnetic field appears to be grounded in the prior experience of viewing a television program about the production of lightning in clouds. Roger's explanation of attractive magnetic force being responsible for bringing electrons together to produce electricity appears to be grounded in his past knowledge and understanding of the physical properties of magnets. Both examples illustrate the power of past experience on subsequent knowledge construction and the overlaying of experiences from home, school, and visits to informal learning centers such as the Sciencentre.

Third, it seems that the interventions sometimes transformed knowledge in both *correct* and alternate ways, despite the best intentions of exhibit designers and the planners of the post-visit activities to provide experiences that would help facilitate knowledge construction in ways consistent with the accepted view of science. This point underscores for teachers, and staff of science museums and similar centers, the importance of planning pre- and post-visit activities not only to support the development of scientific conceptions, but also to detect and respond to alternative conceptions that may be produced or strengthened during a visit to an informal learning center. These findings also reinforce the importance of conducting additional, informal learning research in the areas of knowledge construction and post-visit activity.

Furthermore, it is acknowledged that the major data gathering strategies employed in this study, concept mapping and semistructured interviews at three stages, may have contributed to students' learning by making them more than usually aware of their learning strategies and achievements. However, the data gathering and analysis methods employed in this study, including semistructured and stimulus recall interviewing techniques and independent and discrete analysis of the data sets, helped us to identify and explore instances where experiences not directly related to the Sciencentre visit and post-visit activities influenced students' learning. Indeed, we believe that the understanding thus gained adds substantially to the educational significance of our research. The paths to learning that were followed by the students in this study were rich and diverse, and teachers can begin to understand and exploit them by employing questioning, concept mapping, and post-visit activities, all strategies that are not the sole prerogative of researchers based in academia.

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