DOCUMENT RESUME

ED 286 745 SE 048 584

AUTHOR Clement, John; Brown, David
TITLE Using Analogical Reasoning to Deal with "Deep" Misconceptions in Physics.
SPONS AGENCY Fund for the Improvement of Postsecondary Education (ED), Washington, DC.
PUB DATE 18 May 84
GRANT 6008302557
NOTE 20p.
PUB TYPE Reports - Descriptive (141)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Cognitive Structures; *College Science; *Concept Formation; Higher Education; Learning Processes; *Misconceptions; *Models; *Physics; Science Education; Science Instruction; Scientific Concepts; Secondary Education; *Secondary School Science
IDENTIFIERS *Analogical Reasoning

ABSTRACT

In this paper examples of the role of analogical reasoning in expert problem solving are presented. These are intended to show that using an analogy can change an expert's understanding of a problem situation by changing the conceptual model he or she uses to think about the situation. This suggests that using a good analogy may allow students to overcome a deep misconception by helping them to change the conceptual model they use to think about a physical phenomenon. This pilot study presents evidence from a tutoring interview showing that the use of analogies can help in overcoming misconceptions. The main strategies employed to effect conceptual change (taken from strategies observed in expert protocols) were the use of analogies and specific techniques for confirming these analogies. It is suggested that analysis of such tutoring interviews could lead to a cognitive model for how deep misconceptions may be changed during learning. Potential classroom applications are considered briefly. Several figures are provided. (TW)

USING ANALOGICAL REASONING TO DEAL WITH "DEEP" MISCONCEPTIONS IN PHYSICS

John Clement and David Brown

Department of Physics and Astronomy
University of Massachusetts
Amherst, Massachusetts 01002

May 18, 1984

ABSTRACT

Examples of the role of analogical reasoning in expert problem solving are presented. These show that using an analogy can change an expert's understanding of a problem situation by changing the conceptual model he or she uses to think about the situation. This suggests to us that the right analogy may allow students to overcome a deep misconception by helping them to change the conceptual model they use to think about a physical phenomenon. For example, many students find it difficult to conceive of certain inanimate, "rigid" objects as capable of exerting a force. When asked about a book at rest on a table, they will argue strongly that the table is not exerting an upward force-- it is simply "in the way" stopping the book from falling to the ground. This study presents evidence from a tutoring interview showing that the use of analogies can help in overcoming this misconception. The main strategies employed to effect conceptual change (taken from strategies observed in expert protocols) were the use of analogies and specific techniques for confirming these analogies. In the interview, the subject moves from a strong disbelief of the idea of a table pushing up to "agreeing not just for the sake of agreeing" that the table does exert an upward force on the book. Analysis of such tutoring interviews should lead to a cognitive model for how deep misconceptions may be changed during learning.

This paper was funded in part by FIPSE Grant # 6008302557.

This report describes a pilot study in which we attempt to use analogical reasoning to help students overcome "deep" misconceptions in physics. There is now a fairly extensive literature on students' alternative conceptions in physics showing that students hold fairly consistent beliefs that are often in opposition to the physical theories they are attempting to learn (Clement, 1982). For example, many high school physics students find it very difficult to believe the physicist's explanation that a table pushes up on a book resting on it with a force equal and opposite to the force of gravity. Minstrell (1982) reported that of twenty-seven high school physics students in an upper-income area, more than half did not believe in the force upward from the table.

It has been shown that a number of these alternative beliefs or misconceptions are "resilient" and deep-seated in the sense that they are affected very little by traditional instruction. One reason for this deep-seatedness may be that the beliefs are anchored in physical intuitions that the subject has built up over a long period of time and that he uses with a fair amount of success in dealing with the real world.

In this study we attempted to "fight fire with fire" by appealing to other more compatible intuitions already existing in the student's memory. We assumed that even though the student has one intuition that tells him that a table cannot push up on an object, he may have intuitions that predict upward forces in other situations (such as holding a book on an outstretched hand). We thought that we might be able to utilize one of these other intuitions, by "stretching" its domain of application to include the book-on-table situation. This strategy depends on analogical reasoning, since we are trying to get the student to see an analogy between the book on the table and the book on the hand. In an attempt to focus in on the thinking of individual students, we chose to use a tape recorded tutoring interview setting.

Previous Research

Gunstone and White (1981) used an experimentation and group discussion approach with high ability seventh and eighth graders to teach relationships between force and motion. They concluded that most students did not abandon the Aristotelian view. Hewson (1983) reported some success in changing students' incorrect criteria for identifying equivalent speeds using a microcomputer simulation. Some difficulties pertaining to forces from static objects have been studied by Sjoberg and Lie (1981), Driver (1973), Erickson and Aguirre (1984), Minstrell (1982), and Maloney (1984).

Rosalind Driver devoted a large section of her doctoral dissertation (1973, pp. 184-232) to the interactions of junior high school students in a discovery learning classroom about the existence of an upward force from a table. This research, one of the first descriptive studies of student conceptual understanding of physics, showed clearly the difficulties many students have with the idea of a passive, "rigid" object exerting a force. In her discussion of the results, she suggests looking at the analogies students make for evidence of what aspects of a situation are causing them difficulty. This will hopefully "enable teachers to set up appropriate tasks which will, for example, lead students to the rejection of irrelevant aspects which perceptually may be very appealing."

Minstrell (1982) reports on a classroom lesson devoted to overcoming this misconception. For this lesson, the teacher's main role was to set up a sequence of situations and encourage discussion of these situations.

These included, for example, the book resting on the table and the book resting on a student's han . Class votes were taken at key steps during the lesson, and by the end the number of students believing in the upward force increased from twelve to twenty-five of the twenty-seven students. The success of this lesson seemed to indicate a need for a closer scrutiny of the processes at work. We suspected that analogical reasoning was important in this lesson. The tutoring interview seemed to be the ideal setting for further, in-depth analysis of the effects of an analogical teaching strategy. We have, therefore, conducted a pilot study using a modified version of Minstrell's approach.

Description of Tutoring Strategy

The first step is to suggest an analogous case (such as a hand holding up a book) that the instructor feels will appeal to the subject's intuitions. Hopefully the subject's memory of the muscular effort needed to hold up a book will convince him that the hand pushes up. If the subject still does not believe the hand pushes up, another analogy must be found, or perhaps the extreme case of many books placed on the hand will be convincing (the latter strategy was used by Minstrell, 1982).

Once the subject does believe in the force acting up in the analogous case of the book on the hand, he may still be unconvinced that there is a valid analogy relation to the original case of the book on the table. When this occurs three subsequent teaching strategies can be attempted singly or together.

(1) One can attempt to focus the subject on key features that are the same in the analogous and original cases. This can be done by asking,

"What is the difference between case A and case B?" (e.g., the book on the table and the book on the hand.) This serves two purposes: First, it brings to the subject's mind, perhaps for the first time, the possibility of the analogy relation by requiring him to think of the two situations side by side. Second, it brings to light those features which the subject sees as making the analogy relation unacceptable, thus providing valuable feedback to the tutor.

(2) The second strategy is to attempt to find a third case in between the original case and the analogous case. This is termed a bridging analogy here. For example, one might propose the idea of a book resting on a spring (case C) which shares some features of the book on the table (Case A) and some features of the book on the hand (case B). In the next section we will describe how experts have been observed to look for such cases when attempting to evaluate or confirm the validity of an analogy relation during problem solving (Clement, 1981). We feel that the same approach may be useful as a tutoring strategy for students. The subject may then be convinced that A is analogous to C, that C is analogous to B, and that therefore A is analogous to B.

(3) A third strategy involves making an explicit transformation between the original case and the proposed analogous case. For example, a subject may believe that a ruler suspended between supports will bend when a weight is placed on it, but not believe that a table will bend with a weight on it. If the student is asked to imagine placing a weight on thicker and thicker rulers (or thinner and thinner tables), he may be led to believe that the table bends slightly.

Expert Strategies.

One of the purposes of this pilot study was to see whether our observations of experts resolving conceptual difficulties of their own can inform our attempts to help students resolve conceptual difficulties. A number of strategies are used by experts when they cannot adequately represent a problem situation. W will give examples of two of these strategies here: analogies and bridging analogies. The first concerns the "Wheel Problem" illustrated in Box A of Fig. 2, a question about whether one can exert a more effective uphill force (parallel to the ground) on a wheel at the top or at the level of the axle (in pushing on the wheel of a covered wagon, for example). A number of expert subjects compared the wheel to the analogous case of pushing uphill on a heavy lever hinged to the ground (fig. 2B). They reasoned that pushing at the point higher up on the lever would require less force. They then made an inference by analogy that the wheel would be easier to push at the top (the correct answer).

The second example of an analogy concerns the "Spring Problem" shown in Fig. 1. Essentially, the problem is to decide whether a wide spring will stretch more than a narrow spring, other factors being equal. Several subjects conjectured that this problem might be analogous to the simpler case of comparing long and short rods bent by the same weight. A strong intuition that the longer rod bends more was used to predict the correct result that the wider spring stretches more.

We will also give three examples of "bridging analogies" constructed by experts. In the "Wheel Problem" one subject was confident that it would be easiest to move the heavy lever by pushing at point X, but he questioned whether there was a valid analogy relationship between the case of the wheel and the case of the lever. Can one really view the wheel as a lever, given that the "fulcrum" at the bottom of the wheel is always moving and never fixed? An elegant bridging analogy generated by this subject helped to confirm the appropriateness of the original lever analogy. This is the spoked wheel without a rim shown in fig.2. The spoked wheel allows one to view the wheel as a collection of many levers.

In the spring problem one expert subject was concerned about the apparent lack of a match between the non-constant slope a bug would experience walking down a bending rod and the constant slope the bug would experience walking down a stretched spring. In order to help evaluate the analogy relation between the spring and the bending rod, another elegant bridging analogy was constructed in the form of a spring with square-shaped coils. This allowed him to recognize that restoring forces in the spring come from twisting in the wire as well as bending-- a major breakthrough in his solution which corresponds to the way in which engineering specialists view springs. In this case the square spring analogy eventually acquired the role of a mental model which changed his conception of how springs work.

Another example of an analogy followed by a bridging analogy occurred in a solution to the problem of finding the volume of a doughnut. The subject conjectured that the volume might be the same as the answer to the analogous problem of finding the volume of a cylinder (the "staightened out" doughnut). He thought the length of the cylinder should be equal to the central or "average" circumference of the torus but was only "70% sure" of this. However, he then evaluated the plausibility of this choice by considering the bridging case of a square shaped doughnut (a doughnut made of four straight cylinders; the small cross-section of the doughnut is a circle and the outside and inside perimeters are squares.) He then showed that the four sides of the square doughnut could be reassembled into a long cylinder with slanted ends. He reasoned that the volume of this horizontal cylinder would be its cross section times the length of its base, and that the appropriate length to use in the square doughnut was the average of its inner and outer perimeters. This raised his confidence in his solution to "85%". He then reached the same conclusion for the case of a hexagonal doughnut, and this raised his confidence to "100%" for the problem. Thus the bridging analogy of a square (and hexagonal) doughnut helped the subject change his original conjecture about the cylinder analogy into a firm conviction. In summary, bridging analogies strike us as one of the most insightful and effective strategies for confirming the validity of a model and increasing understanding that we have observed.

Preliminary results

Several students have been tutored individually in a pilot study utilizing two of the tutoring strategies mentioned above; matching key features and bridging analogies. The sessions were each tape recorded. The following transcript excerpts illustrate the approach. The subject, a humanities graduate student with no background in physics, was instructed that if she expressed a view on a question, the interviewer might take the opposite view in order to generate discussion. The subject was asked to maintain her views unless it seemed reasonable to her to change her views. After these instructions she was asked the following question: What forces are there on a book resting on a table?

S: I don't want to put an arrow up but I feel like this (circle representing the earth) is forcing that (book) to come down.
I: Like the earth is forcing the book to come down?
S: Yeah, and the table gets in the way. So that's why the book stays.
I: But the table isn't pushing back on the book?
S: How can a table push back on a book? (Laughter)

The tutor now introduces the analogous case of the book on the hand.

I: If I were to put the book on your hand, if you were to hold out your hand, and you just held it there, would you be pushing back on the book?
S: Yeah
I: You would be?
S: I'm taking the book. I'm putting it on my [hand] I'm, yeah, I'm pushing against the book cuz if I don't the book is heavy enough that I'd drop it if I don't push against it.

The subject believes that the hand pushes up. However, the subject is unsure that this is analogous to the case of the table, as shown below.

I: The case with your hand is different than with the table?
S: Well, the table just doesn't have a choice on what it does, where I have the choice about how I move my hand.
S: I mean in a way I can understand how you can say the table is pushing against the book except it's not the same type of push...I can relax my hand, while the table is, it's just there...it cannot relax itself to allow the book to fall any further...this (table) is immobile...so I guess that's how I see pushing because I'm actively pushing.

Notice the subject's misconceptions about force: 1) Volition is involved, "the table just doesn't have a choice," and, "I can relax my hand," and; 2) the source of force is active, "I'm actively pushing."

Here the book on S's hand has been given as an analogy to the book on the table in an attempt to help her see the table as pushing back on the book. That is, one hopes that the subject will believe in a force up from the hand on the book, and that this will make a force up from the table more plausible. There was a glimmer of success; "I mean in a way I can understand how you can say the table is pushing against the book." However, the subject does not appear to be convinced. Now another analogy is attempted which is an intermediate bridge between the table and the hand in hopes that this will make the first analogy relation more plausible. The bridging case consists of placing the book on an imaginary spring of about the "springiness" of a bedspring. The spring shares with the table the features of being inanimate and non-volitional. It shares with the hand the feature of being obviously capable of motion.

> I: Would you say that the spring is pushing on the book?
> S: I suppose you could say that in a reverse manner, but not--so why doesn't the table push on the book? (laughs) Umm, again it just seems like the spring is being acted upon, I mean, I guess in a way you could say it's pushing against it, yeah I guess you would say it's pushing against it.
> I: You said something about a reverse manner?
> S: Well just because I think of--if you put something on a spring, that something makes the spring go down, but I guess if you see it another way the spring is also holding that thing up from going, as uh, as far as it wants to go down.
> I: So do you see that as a different kind of push than the push you were giving with your hand on the book?
> S: (Pause) In one way yes, in one way no. I guess there seems to be more action in the spring than there is in the table, but it's still--my hand, I control my hand while the spring again is one of those things that it can't control its response to whatever is being placed upon it. But I guess it does have more of, it seems to have more of a, uh, impact on pushing back something than a table would.

This bridge between the first analogy and the original situation seems to have had some impact on S, even though she still remains to be fully convinced. The situaton is shown in Fig. 3. Case C was proposed as a bridge from case A to case B. Now the interviewer sets out to build a bridge from B to C and then from C back to A. After a series of analogies, most of which were generated by the interviewer but some by S, she is brought to the point at which it seems reasonable to her to say the table pushes back. The final analogy, the last link in this process, is documented below. I tells S that the table bends when the book is placed on it. S does not believe this and asks I to prove it.

I: Right. It's when you put this pile of books on it, it's not bent very much but it is, it does bend a very slight amount...
S: But you're saying, even though with this amount of books on it this table is bending slightly?
I: Yes
S: How can you prove that? (pause) So you're saying that all things will bend? No matter, does it matter...
I: Well on the microscopic view if you wanted to look at it that way, um, a table, would you agree that the table is composed of molecules?
S: Sure.
I: And molecules, um, basically what they are is they're connected by bonds which are flexible, that are sort of like springs, they might be pretty stiff springs, but they're sort of like springs. And so this table is composed of, this is in drawing 3, each of these little circles is a molecule. You can think of it as being composed of a group of molecules which are attached by springs, each molecule has what s called a bond with other neighboring molecules which is something like a spring. It's not a literal spring, but it acts like a spring.
S: Mmm
I: ...a group of springs and I put this other group of springs on top of it, which is the book
S: Mmm hmm
I: and the two things kind of
S: Push against each other
I: Push against each other, right. Does that make sense at all?
S: Yeah that makes sense. So I can see why you would say the table would move.
I: So you're saying the molecules [picture] was helpful to you?
S: That was the most helpful, seeing the composition as being springs against springs, but, you know, the other ways, I would have just been agreeing with you for the sake of agreeing.
I: But the springs as molecules that did (help)?
S: Yeah, that did.
I: So if I were to ask you is the table pushing against the book what would you say now?
S: The molecules in the table are pushing against the book. (laughs)
I: Okay now, what would you say if I were to ask you: "Is the table pushing against the book?"
S: The table pushing against the book? I could understand why you would say that. Molecule speaking.

In this last section, the tutor proposes that the spring and the table share the common property of deforming under a force. He also proposes a new bridging analogy between the books on the spring and the books on the table. This bridging analogy takes the form of an image of the table being made up of molecules connected by stiff springs. This analogy serves as a model which provides an explanation for the bending property of the table. The explanation then finally seems to "make sense" to the student, after a fairly long prior period of disbelief on her part.

The right bridge can help a student see why a standard physical model is a good way of viewing phenomenon A. Presumably, this method works because it is easier to comprehend a "close" analogy than a "distant" one. The bridge divides the analogy into two smaller steps which are easier to comprehend than one large step. Using the term "bridge" in a more general way, we can say one of the teacher's most important jobs is to help students build bridges from their intuitive conceptions to the standard conceptions in the curriculum.

We have only been able to present excerpts from this exploratory tutoring session here. The entire session was considerably more involved, as indicated in Fig. 4. This figure shows a map of the major analogies generated during the interview. It is significant that many were generated by the subject as well as the investigator. A key is provided to aid interpretation of the diagram.

Connection to Classroom Teaching

The tutoring strategy used in this study needs some modifications in order to apply it to classroom instruction. Individual students differ in the strength of their beliefs in various preconceptions, and the classroom teacher cannot respond individually to each student. However, we have had some success in generating discussions in a high school classroom by using the same basic strategy. These discussions were quite animated. The conflicts between the strongly held views of different students were useful in that they seemed to be a powerful agent in promoting interesting debates. Minstrell (1982) reported fairly good results in using a slightly less structured approach. Thus, we have reason to believe that the strategies developed will be important in group instruction as well.

Summary

We have only considered a single subject in this paper, but such case studies are an important first indication that an interesting tutoring method has been found. The protocol provides evidence for the student making some progress in changing her ideas at a fairly deep conceptual level. A misconception which is quite deep-seated in many students has been supplanted with other ideas. The main principles used in this approach are (1) Socratic tutoring--in which questions posed to the student encourage her to become actively involved in learning; (2) Using key examples to activate useful intuitions possessed by the student; (3) building on and extending those intuitions by using analogical reasoning, and in particular, using the strategy of "bridging analogies" that has been observed in the solutions of experts problem solvers. Analyses of such transcripts should allow us to greatly increase our understanding of the learning processes involved in overcoming deep-seated misconceptions.

REFERENCES

Clement, J., "Students' Preconceptions in Introductory Mechanics," The American Journal of Physics 50, 66-71 (1982).

Clement, J. "Analogy Generation in Scientific Problem Solving." Proceedings of the Third Annual Meeting of the Cognitive Science Society, Berkeley, California, August, 1981.

Driver, R., "The Representation of Conceptual Frameworks in Young Adolescent Science Students" Ph.D., dissertation, University of Illinois, 1973.

Erickson G., and Aguirre, J., "Student Conceptions about the Vector Characteristics of Three Physics Concepts," J. Res. Sci. Teach. 21, No. 5 (1984).

Gunstone, R., and White, R., "Understanding of Gravity," Science Education 65, 291 (1981).

Hewson, P., "Microcomputers and Conceptual Change: The Use of a Microcomputer Program to Diagnose and Remediate an Alternate Conception of Speed," paper presented at the annual meeting of the American Educational Research Association, Montreal, Quebec, Canada, 1983.

Maloney, D. P., "Rule Governed Approaches to Physics: Newton's Third Law," Physics Ed. 19, 37-42 (1984).

Minstrell, J., "Explaining the 'At Rest' Condition of an Object," The Physics Teacher 20, 10-14 (1982).

Sjoberg, S. and Lie, S., "Ideas about Force and Movement among Norwegian Pupils and Students," Technical Report 81-11, University of Oslo, 1981.

SPRING PROBLEM

A WEIGHT IS HUNG ON A SPRING. THE ORIGINAL SPRING IS REPLACED WITH A SPRING

--MADE OF THE SAME KIND OF WIRE,

--WITH THE SAME NUMBER OF COILS,

--BUT WITH COILS THAT ARE TWICE AS WIDE IN DIAMETER.

WILL THE SPRING STRETCH FROM ITS NATURAL LENGTH, MORE, LESS, OR THE SAME AMOUNT UNDER THE SAME WEIGHT? (ASSUME THE MASS OF THE SPRING IS NEGLIGIBLE COMPARED TO THE MASS OF THE WEIGHT.) WHY DO YOU THINK SO?

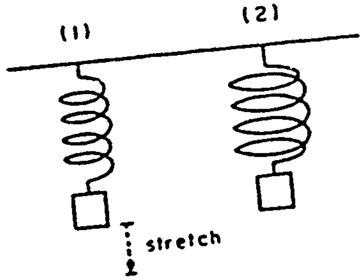


FIGURE 1

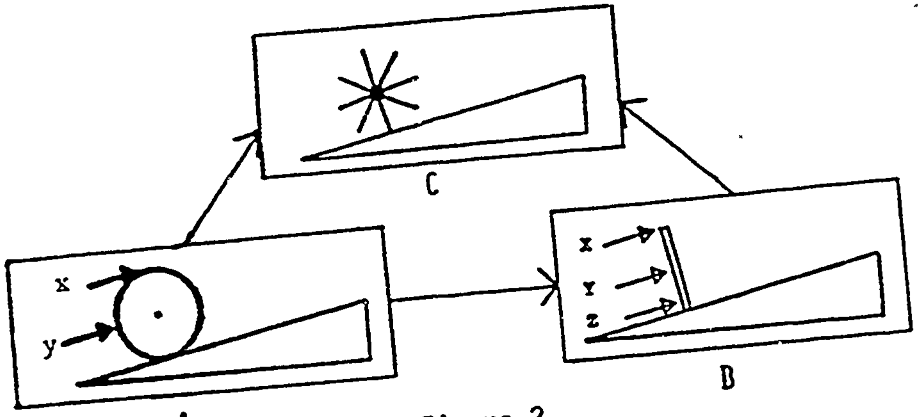
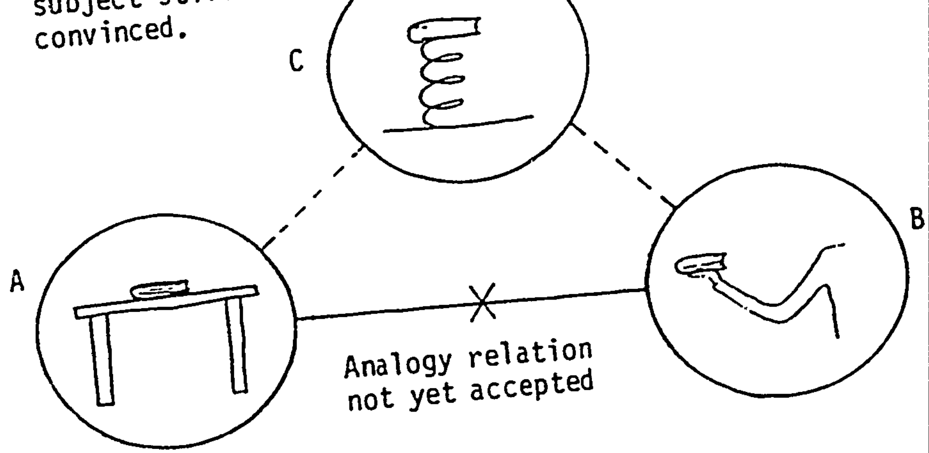
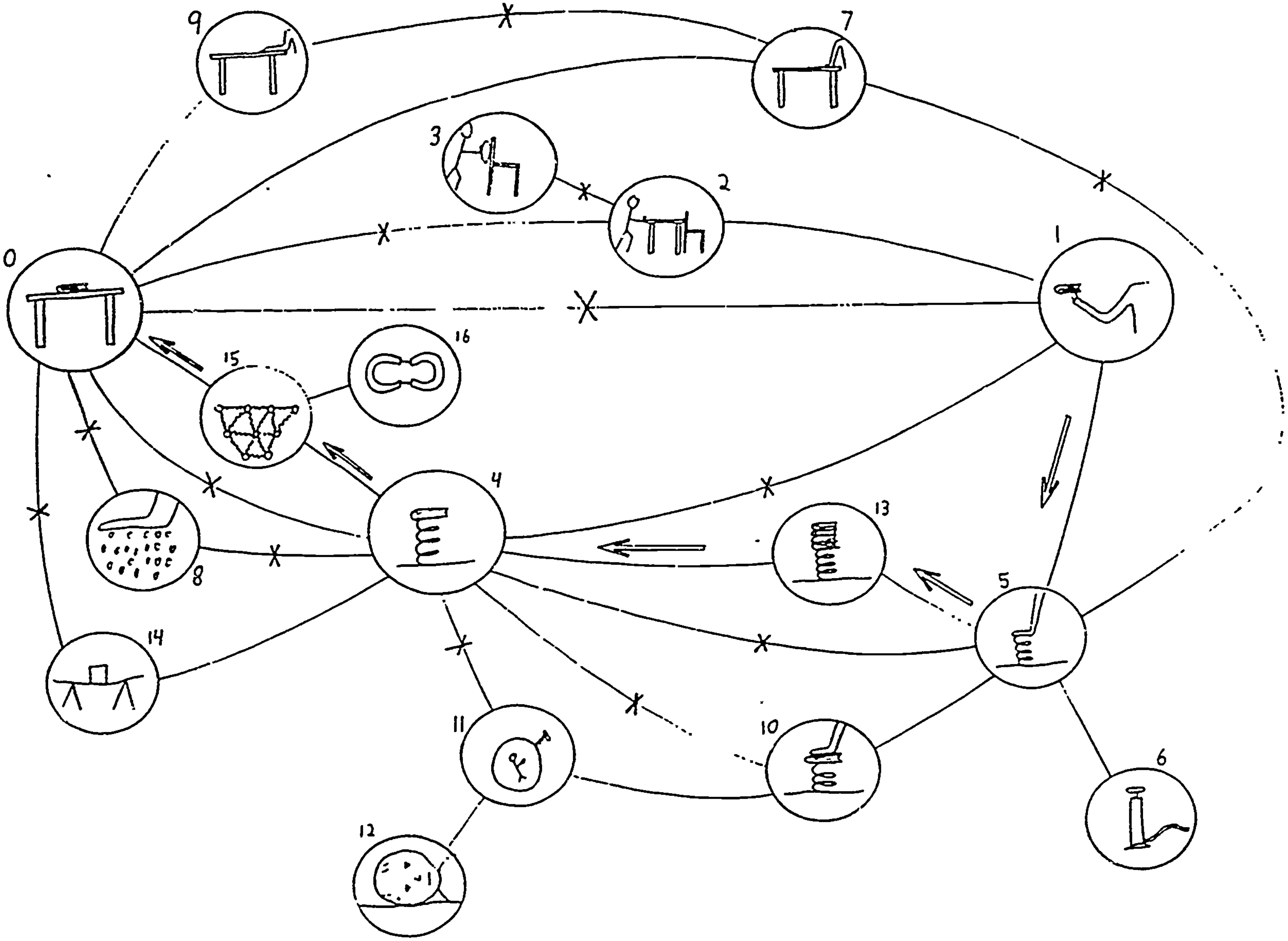


Figure 2

Figure 3



INTERVIEW SUMMARY: DIAGRAM OF ANALOGIES CONSIDERED



X - Analogy relation not accepted by subject

For further explanation see key

Arrows - Indicate final success path

Figure 4

INTERVIEW SUMMARY KEY

NUMBER	DESCRIPTION	GENERATED BY	ACTUAL (E) or THOUGHT EXPERIMENT (G)	PERSONAL (P) or NON-PERSONAL (N)	OCCURS ON TAPE
0	Book on Table	I	E	N	A020
1	Book on Hand	I	E	P	A080
2	Table Pushing Chair Table exerts force	S	G	P	A124
3	Balloon Pushing Chair Does not exert force	S	G	P	A127
4	Book on Spring	I	G	N	A156
5	Hand on Spring	I	G	P	A238
6	Bicycle Pump pushes back on hand	S	G	P	A278
7	Push on Table	S	G	P	A313
8	Push Molecules in Table	S	G	P	A313
9	Arm Resting on Table	S	G	P	A320
10	Push Book on Spring	I	G	P	A480
11	Pull from the Center of the Earth	I	G	N	A502
12	Head on Ground if pull From center of earth	S	G	P	A505
13	Pile of Books on Spring	I	G	N	B088
14	Block on Bar - bends Pushes back	I	G	N	B100
15	Molecules Connected by Springs	I	G	N	B170
16	Magnets	I	G	P	B180

The analogies are listed in the order they appeared on the tape. First a number is given corresponding to the number on the diagram, and a short description of each analogy follows. The next three columns tell who generated the analogy (Interviewer or Subject), whether the situation involved actual or imagined objects, and whether the situation personally involved the subject.