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ABSTRACT

Analogies and examples from student's experiences are frequently cited as important to teaching conceptual material. This study was conducted in order to explore the effectiveness of an analogical teaching technique, which uses a connected sequence of "bridging" analogies, compared with a more standard teaching-by-example technique. The target concept involved the common misconception that static objects are unable to exert forces. Of the 21 high school students with no prior physics instruction who were individually interviewed, 14 initially maintained that a table does not exert a force upward on a book resting on it. The latter were divided into two matched groups. Students in each group were asked to think aloud as they worked through one of the two written explanations. After instruction, the experimental group performed significantly better on target and transfer problems, as well as indicating significantly higher subjective estimates of how "understandable and believable" the explanation was. These findings suggest that: (1) teachers need to be aware that certain examples they themselves find compelling may not be at all illuminating for the student; (2) even when the example is compelling to the student, it may not be seen as analogous to the target problem in the lesson; and (3) teachers need to keep in mind the goal of helping students develop visualizable, qualitative models of physical phenomena. (Author/ML)

OVERCOMING MISCONCEPTIONS IN MECHANICS: A COMPARISON OF TWO EXAMPLE-BASED TEACHING STRATEGIES

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ABSTRACT

Analogies and examples from students' experiences are frequently cited as important to teaching conceptual material. However, little research has been done concerning the best use of examples in attempts to remediate misconceptions. This study was conducted in order to explore the effectiveness of an experimental analogical teaching technique, which uses a connected sequence of "bridging" analogies, compared with a more standard teaching-by-example technique. The target concept involved the common misconception that static objects are unable to exert forces. Of the twenty one high school students with no prior physics instruction who were individually interviewed, fourteeen initially maintained that a table does not exert a force upward on a book resting on it. The latter were divided into two matched groups. Students in each group were asked to think aloud as they worked through one of the two written explanations. After instruction, the experimental group performed significantly better on target and transfer problems, as well as indicating significantly higher subjective estimates of how "understandable and believable" the explanation was. These findings, along with descriptive analyses of protocols, indicate three important implications for teaching. First, teachers need to be aware that certain examples they themselves find compelling may not be at all illuminating for the student. Second, even when the example is compelling to the student, it may not be seen as analogous to the target problem in the lesson. Finally, teachers need to keep in mind the goal of helping students develop visualizable, qualitative models of physical phenomena.

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INTRODUCTION

Current research on student learning and understanding in science underscores a significant problem in epistemology: contrary to the commonsense theory of learning which implies that all that is necessary is to open our minds to knowledge flowing in through our senses, learning appears to be the result of a complex interaction between pre-existing knowledge structures and sensory experience. Typically students come to the science classroom, especially the physics classroom, with a number of alternative conceptual frameworks which can inhibit the learning and understanding of certain concepts (see McDermott, 1984, for a review of some recent studies). Many alternative conceptions are both widespread and resistant to change; traditional instructional approaches have often had little impact on them (see Halloun and Hestenes 1985 for a study of wide scope indicating both the adverse effect of misconceptions on course performance and the ineffectiveness of traditional instruction in remediating them). These naive student beliefs have a detrimental effect on problem solving, course performance, and the ability to acquire conceptual understanding of the material.

A number of attempts have been made to deal with the problem of misconceptions, but only a very few studies have examined the use of thought situations (such as examples, analogies, and thought experiments) as a possible means of helping students modify their alternative conceptions. Historically, thought situations have been important in the development of science (cf. Kuhn, 1977). A prototypical example is Einstein's famous thought experiment about what would happen inside an elevator if the cable were cut. According to Einstein, this thought experiment was crucial in his development of the theory of relativity, a theory which brought about a revolution in scientific thought and gave scientists a new conceptual framework through which to view the world.

The power of thought situations in science education has been little explored. If students are led to consider in some depth carefully chosen thought situations, this may have an impact on the problem of misconceptions. Although the use of analogies and examples is encouraged by a number of educators, very little consideration has been given to exactly how thought situations should be used in the presence of misconceptions. Typically teachers and textbooks will supplement their didactic presentations with examples and analogies which they themselves have found helpful, but the students may or may not find them illuminating. If the analogies or examples are not particularly helpful, work needs to be done to discover how better to use thought situations.

The purposes of this study are twofold: first, to explore whether students' consideration of thought situations alone (i.e. without additional empirical experiences) can have an impact on their misconceptions; and second, to examine whether different methods of using thought situations have different effects on students' misconceptions and the reasons for these differences if any exist. In order to explore these questions, we examined two methods of using thought situations.

The first method is to treat the thought situations as concrete examples of an abstract principle; here the thought situations are intended to ground the principle in the students' experiences. The primary focus of this type of explanation is the abstract principle, with the thought situations serving to show applications of the principle. The student should then be able to apply the principle to other situations which are similar to the examples, such as a target problem for which the student has a misconception. The second way of using thought situations is to treat them as the primary focus of the explanation. The student is led through a connected sequence of analogies beginning with an "anchor" (a situation for which the student believes intuitively that the Newtonian answer is correct), through intermediate situations or "bridging analogies," to the target problem (cf. Clement and Brown, 1984). Here the thought situations are intended to help the student apply correct intuitions about an analogous problem to the target problem. Initial investigations of this method drew inspiration from analyses of experts' strategies in attempting to solve conceptually challenging problems (cf. Clement 1982, 1986).

DESIGN OF THE STUDY

Subjects

For this study, twenty one high school students were interviewed who had not yet taken physics, but who came from a population representative of students who might subsequently take physics (in this case, chemistry students). Each of the students received one of two different explanations (these will be described in more detail below). In order to insure that neither the experimental group nor the control group had a higher average intellectual ability, the teachers were asked to rate the students on a binary scale as having a relatively easy or difficult time with conceptual material. Combined with the information about which level chemistry course each student was taking (advanced or standard), each student was assigned to one of four sub-groups. Half of the students in each sub-group were chosen at random to receive one explanation, and the other half received the second explanation.

The explanations

The control explanation shown in Appendix I contains a verbatim excerpt from a popular and innovative high school textbook[1] which gives a number of examples of Newton's third law. Some of the examples used are a finger pressing on a stone (one of Newton's own examples; the stone presses back on the finger), an athlete running (the ground pushing forward on the athlete is responsible for her motion), and a rifle kick. Added to this verbatim excerpt were two sentences at the beginning and a final paragraph explicitly stating that Newton's third law applies to the book on the table situation, and that therefore the table is exerting an upward force. (Note: Because of these additions and the fact that the students reading this explanation had not read the prior material in the text, any failings of this explanation should be viewed as failings of this particular treatment rather than necessarily as a failing of the text itself.)

The experimental explanation also makes use of concrete situations from the students' experience, but unlike the first explanation, they form a connected sequence, starting from an "anchor" (a situation for which we know that most students believe there is an upward force, in this case a hand pressing down on a spring), through intermediate situations (e.g. a flexible board between two sawhorses), to the target situation of a book on a table. Thus this explanation shows, by means of this connected sequence of examples, where the force comes from - the microscopic compression or bending of the table.

This explanation is designed to: 1) ground understanding on an anchoring intuition that the student already possesses; 2) help the student develop a conviction that the target problem is in fact analogous to the anchoring case; and 3) build a qualitative, microscopic, causal model of rigid objects (as composed of molecules connected by spring-like bonds) which is also based on the anchoring intuition. By helping the student form an analogical connection from the anchor to the target situation, the experimental explanation helps the student construct a causal model of the table which predicts an upward force. (See the Appendix I for the actual explanations used. The differences between the two explanations are illustrated in figure 1.)

The questions

Each student received a set of three pre-questions and five post questions (three identical to the pre-questions plus two additional questions - see Appendix II for the actual questions used). The purpose of each explanation was to overcome the common misconception that static objects cannot exert forces, thus all the pre and post questions were questions about this general concept. Except for the first question about the book on the table (which asked only about the existence of a force from the table), each question asked both about the existence of a force from a static object, and also whether that force is equal to the force exerted on it.

Each question asked the student to rate his or her confidence in the answer given, and the interviewer also asked the student to rate how much sense their answer made. Being confident about an answer and an answer making sense were carefully distinguished for the student (see Appendix III). The main reason for this distinction is to try to uncover what students intuitively feel is correct rather than what they may confidently know is correct because they happen to remember something in a rote fashion from a television program, a previous science course, or a discussion with a friend taking physics. During the course of reading aloud the written explanation, after each paragraph the student was frequently asked how much sense a particular statement made, along with other probes both to explore his or her reasoning during the explanation and to encourage interaction with the explanation.

RESULTS

Of the fourteen students initially maintaining that there is no force from the table, seven received the control explanation and seven received the experimental explanation. To the "Book on the Table" post-question, all seven receiving the experimental explanation expressed a confident belief in an upward force from the table. However, of the seven receiving the control explanation, five answered the table problem incorrectly after reading the explanation, even though the explanation had explicitly stated the correct answer to this problem. There were also significant differences in performance on the other post-questions in favor of the experimental explanation. Brief descriptions of the five problems follow.

Question 1 asked only about the existence of a force from the table. Questions 2 through 5 asked both about the existence and the relative magnitudes (or equality) of the forces between other static objects. Question 4 concerns a non-example in that the forces to be compared are not equal. Following are some tables of results for the fourteen students initially indicating that the table does not exert an upward force. Seven of these received the control explanation, and seven received the experimental explanation.

In tables 1 and 2 the first three columns indicate the number of students answering correctly for each part of each problem before reading the explanation. The first two columns show the number of students answering correctly about whether there is a force from the static object, and whether the forces to be compared are equal or not. The overall score indicates the total number of correct answers for each problem. The next three columns contain the same quantities for the questions asked after the students had read the explanations. The last column indicates the pre-post differences between the pre and post overall scores. Table 3 then compares these overall pre-post differences. (Note: Since questions 4 and 5 were asked only after the explanation, they do not have pre-explanation scores and table 3 compares the overall post scores.) In addition, table 3 presents a comparison of students' ratings in response to two questions asked after the explanation: 1) was the explanation understandable and believable, and 2) did the explanation help the idea of an upward force from the table make sense. For both of these questions, a 5 indicates the best possible rating.

NUMBER OF STUDENTS ANSWERING CORRECTLY:
CONTROL EXPLANATION

	Pre-questions			Post-questions			Overall
	Exist.	Equal.	Overall	Exist.	Equal.	Overall	pre-post
1) Table	0	-	0	2	-	2	2
2) Goat	2	1	3	4	2	6	3
3) Mosquito	1	0	1	2	2	4	3
4) Two boxes	-	-	-	4	1	5	
5) Steel blocks	-	-	-	3	0	3	

Table 1

NUMBER OF STUDENTS ANSWERING CORRECTLY:
EXPERIMENTAL EXPLANATION

	Pre-questions			Post-questions			Overall
	Exist.	Equal.	Overall	Exist.	Equal.	Overall	pre-post
1) Table	0	-	0	7	-	7	7
2) Goat	3	2	5	7	6	13	8
3) Mosquito	1	1	2	7	7	14	12
4) Two boxes	-	-	-	7	5	12	
5) Steel blocks	-	-	-	7	6	13	

Table 2

COMPARISON OF OVERALL PERFORMANCE

	Control	Experimental
Pre-post differences		
1) Table	2	7 **
2) Goat	3	8
3) Mosquito	3	12 **
Post scores		
4) Two boxes	5	12 *
5) Steel blocks	3	13 **
Student ratings of explanations		
Understandable and believable?	3.4	4.7 **
Helps to make sense?	2.9	4.7 **

* $P < .05$ Difference in favor of the experimental group
** $P < .01$

Table 3

These results indicate that the students responded differently to the two explanations. All of the students initially answering the table problem incorrectly and who received the experimental explanation answered the post question about the book on the table correctly and with high confidence (average confidence score of 2.8 out of 3). They also indicated that this answer made a great deal of sense to them (average sense rating of 4.6 out of 5), and their performance on other post questions was quite encouraging. Particularly encouraging is the fact that six of the seven students answered both parts of the steel blocks problem correctly, a difficult transfer problem which draws out the strong intuition in many students that force is a property of objects. Many thus answer that block A exerts the larger force since it is heavier. On a recent high school diagnostic test, after a full year of traditional instruction in physics, from a sample of 50 students only 24 answered this problem correctly (unpublished data).

By contrast, of the seven students who initially answered the table problem incorrectly and who received the control explanation, five answered the table problem incorrectly after reading the explanation, continuing to maintain that the table does not exert an upward force on a book resting on it. Their performance on other post questions was equally discouraging. In particular, none of them answered both parts of the steel blocks problem correctly. Several possible reasons are explored in the following section for the observed differences in student reaction to the two explanations.

DESCRIPTIVE OBSERVATIONS AND DISCUSSION

Induction - sometimes ineffective

As the above results indicate, despite the fact that the control explanation stated a principle which was supported by a number of examples from the students' experience, and also that the explanation explicitly stated that the book on the table was another example of the stated principle, the majority of the students continued to maintain the absence of a force from the table. There are two possible reasons for this failure: 1) the students did not realize that the principle explicated in the control explanation (Newton's third law) should apply to the book on the table situation, or 2) they realized the principle should apply, but they simply refused to accept this conclusion. Because the explanation explicitly stated that the book on the table was an example of Newton's third law, it is difficult to accept the first reason. Students' statements do in fact provide support for the second reason. Following are one student's reasons for this rejection.

S: "A book is at rest on a table. Which of the following do you think is true?" The only thing is if I answer this, I know, said that Newton's Law said that it does. But, okay they want what I think. I still think that it doesn't. And I'm pretty confident about that. And why I don't think it does is because I haven't been given enough evidence to prove that it actually does. I mean, I can only handle so much physics-type things. You know, gravity is about the extent of my physics mind. And to say that there's forces beyond thinking, beyond, you know any control of the human being, you know pushing up on a book, or even the book pushing down on the desk, are odd. The only reason I know that the book is pushing down on the desk that's just because gravity is a real force it's a magnetic force. You know out in space where it's outside of the magnet, the book would stay right in mid-space and would not fall. That's why.

Gick and Holyoak (1983) report a study in which they conclude that a person presented with multiple analogies induces an abstract schema which aids consideration of analogous situations. However, Kaiser, Jonides, and Alexander (1986) describe a study very similar to Gick and Holyoak's in which they explored the effect of analogous problems presented before target problems. However, unlike Gick and Holyoak, prior experience with one or two analogous problems had no effect on subsequent performance on the target problem, the subsequent path of a ball that has been rolled through a curved tube, a problem which reveals misconceptions in many subjects (cf. McCloskey, Caramazza, and Green, 1980). The more familiar analogs, for which subjects more frequently answered correctly, were water coming out of a curved hose and a bullet out of a curved gun barrel.

They conclude that the reason for this lack of analogical transfer is due to the subjects' finding differences between the "analogous" situations, such as the speed and the substance of the issuing projectile. This seems to indicate that when a student has a misconception, it may not be an appropriate instructional strategy simply to present the student with multiple examples in hopes that he or she will induce an abstract concept from the examples.

This certainly appears to be the case in the present study. When students were presented with multiple examples illustrating an abstract principle, most refused to accept a conclusion which they found counter-intuitive. In contrast, when students were presented with a sequence of bridging analogies which explicitly illustrated the analogical connection between the book on the table (the target problem) and the hand on the spring (a conceptual anchor) by demonstrating similar underlying structure (springiness), the students did not hesitate to accept the conclusion that a static object can exert a force. This suggests that some learning situations may require the explicit development of analogy relations in addition to the simple presentation of examples.

Three reasons emerged from examination of the protocol data as possible explanations for the differences in student reaction to the two methods of using thought situations. First, the anchoring examples used must make sense to the students, not simply to the teacher or textbook author presenting them. Second, analogical relationships which are obvious to the instructor need to be explicitly developed for the student. Third, it may be important to develop qualitative models which give mechanical explanations for phenomena. Examples from protocols which support each of these factors are given in the next three sections.

Examples must make sense to the students

Several of the examples in the control explanation made little sense to some of the students. The two segments below illustrate typical student responses for the two examples of the ground pushing forward on the runner and the stone pushing on the finger.

I: Does it make sense to you that the ground pushes forward on the athlete?

S: Um, -- give me one second and I'll see if it does. --- (15 secs)-- Honestly? Not a whole lot of sense...I can't really understand the logic behind saying that it, the ground involves a push of the ground forward on her.

I: Does it make sense to you that the stone would push back on the finger?

S: Um, not a lot of sense. I mean, I could figure, granted, your finger bends and you can feel the stone on your hand. Um, it doesn't make a lot of sense to me that it pushes back...I have to admit that I only see things that don't move as not exerting a force, a counter force, or an interactive force as they're calling it, but more as a resisting force.

By contrast, most of the students indicated the examples in the experimental explanation made a great deal of sense. The average sense rating for the control examples was 3.3 out of 5 (the examples made only slightly more than some sense to the students), whereas the average rating for the experimental examples was 4.6 (the examples made slightly less than perfect sense to the students). This difference is significant at $p < .001$. However, as the following section shows, simply having good individual examples may not be enough.

Need to explicitly develop analogy relations

Many teachers and textbook authors supplement their presentations with analogous examples. However, perhaps because the analogies are to them "obviously" analogous, no attempt is made to explicitly develop the analogy relations. The present study indicates that the use of thought situations in this way may be ineffective. For example, even though the physicist views the book on the table and the hand on the spring as completely analogous situations, six of the seven students given the experimental explanation did not. An example is given below.

I: Is this different from the book on the table?
S: The spring on the hand?
I: Yeah.
S: Yeah, I think so.
I: How so?
S: Because the table isn't forcing your hand up, and you don't have to put any pressure on the table so your hand doesn't come back up. With the spring you have to put some pressure on the spring so it doesn't push your hand up. Do you know what I mean?
I: I'm not quite sure I...
S: Well, you're talking about pressing down on the spring, right?
I: Right.
S: If you press down on the spring there's some pressure from the

spring to push your hand back up.
I: Uh huh
S: Put your hand on the table there's no pressure whatsoever pushing your hand back up.

However, when the analogy relation between the hand on the spring and the book on the table was developed, this subject saw the hand on the spring as an appropriate analogy. After he had read the entire explanation, he began to indicate that he believed the spring analogy did not help, but then he realized that a "way has been built up" from the spring to the table by means of intermediate analogies.

I: Ok, let me ask you, which examples on this page helped the idea of an upward force from the table make sense and which did not help?
S: I don't think the spr.., well, I guess I didn't think the spring helped, but in context I guess, out of context you just compare the spring and the table it wouldn't help, but you sort of built a way up from the spring, which is obvious, to a flexible board, to a not so flexible board, to foam rubber, to a table, which is pretty good.
I: Were there any examples that didn't help?
S: No, I don't think so.

The following segment also illustrates the importance of developing analogy relations. Initially the student indicated that she did not believe the table exerted an upward force, and when she read about the spring analogy, she curtly dismissed it as simply not analogous to the table. However, after intermediate analogies had been presented, she decided that the table does in fact exert an upward force. (Note: This subject was involved in a pilot study prior to the present study. The sections in quotes are sections she read from the written explanation. A significant portion of the transcript is presented verbatim with only minor deletions for easier readability.)

S: "Many people say the table is not exerting an upward force, it is just in the way. However, consider pushing down on a spring with your hand. Does the spring exert a force back on your hand? Is this different from the book on the table?" Yeah, the spring's moving, the table's not. So, that's all I have to say about that one. Umm, "Now consider the case of a heavy dictionary being placed on a bedspring so the squish, the spring squishes down some. Does the bedspring exert a force up on the book?" Oh, they get confusing now, it's still not moving, but it's exerting a force.

I: What was that?

S: It's still not, well, it's still not moving, right, cause the book just squished it, but, oh, I get it! See now, the spring's moving, this is a, this is a good way, talk about a spring, it makes it a little more understandable. If the book's like pushing down on the spring, and then the spring is still in a way pushing up, and it's stopping the book from going down any further, so yeah, it'd be exerting a force. But I guess that's the same thing as a table, but a spring is a lot easier to understand than a table that's not moving, even if it is preventing the movement of something. Ok, "Is this different from the book on the table?" Well I guess that's kind of what I just said. That I guess it's a little different, but, um, ok. "Many people say it is different. They say that although neither is alive, the spring squishes down but the table is rigid. But is the table rigid? Imagine a flexible board between two sawhorses. If you were to push down on this board it would bend and push back, just like pushing down on the spring. The board would also push back on a book, just like the spring. Now imagine thicker and broader boards. Is the book on the board situation different from the book on the table?" Hey I'm learning something here. Um, maybe in a small little way it squishes the table. But it's a lot harder to imagine a table moving than like a spring or a board.

I: You said you're learning something? I was just wondering what you meant.

S: Well, because, in the beginning there was, it didn't seem to me that the book, that the table would be exerting a force...When you come down here it sort of explains it, like the spring was a good example because you sort of understood that something was pushing it back up and preventing it from moving and therefore was like a force on it...And as they go down here and show examples going from a spring to a weak board, then you could go to a table, and it would make more sense to me that a table was, was exerting a force on the book. That's all I meant when I said I was learning something that at least I had a little bit more of an understanding why I thought that was happening.

Mechanistic models are important

The experimental explanation gave students a mechanistic model for the source of a force from a table, the table as composed of molecules connected by springy bonds compressing on contact with other objects. This model gives students a reason for why the table exerts a force. Such a mechanistic model was lacking in the control explanation. The absence of a source for the force troubled several of the students, as illustrated by the segment below.

I: Can you summarize the main idea of this explanation?
S: Um, well they're trying to tell me that, um, for every force there's an opposite force that happens against it. But they still haven't told me where it [the force] comes from or why, and I have no intention of accepting it until they do.

The absence of a mechanistic model may have lead students to think about force in their usual way, which often meant thinking of it as a property of an object rather than arising as a result of an interaction. Following is an example of such thinking in the steel blocks problem, a problem for which many students answer that the larger block exerts the larger force because it "has" more force. (Note: this student was one of the two who answered the table problem correctly after reading the control explanation.)

S: "A large steel block weighing 200 pounds rests on a small steel block weighing 40 pounds as shown. Think about whether A exerts a force on B, and whether B exerts a force on A." Ok. "Does B exert an upward force on A?" Yes. And I'm sure I'm right, and um, it makes perfect sense to me because I mean, I think it exerts a force up, but I don't think it exerts enough to stop A from pushing B into the ground. See, it just makes the thing slower. So say B only weighed one pound, then A would have 199 pounds more than B would, and so it would push it into the ground faster. But this way, B has some force, it has a larger force than before, but not enough to keep A from pushing it down into the ground...Hard to think about this one because in the ones before where the light thing was on top, the heavy thing just used enough to fend off, you know, to keep the lighter thing on top. See, so it's a matter of how much force the thing uses. So I'd say that, uh, A and B exert a force on each other, but A exerts a larger force. I'd say I'm fairly confident about that.

By way of contrast, the following student discovered in the experimental explanation a more appropriate way of thinking about the steel blocks problem. Although he initially answered correctly, he did have some trouble making sense of the problem. He was drawn into viewing the problem in the same way as the above student, a perspective which implies that the larger block would exert the larger force. He was unsure whether the 40 pound block could exert 200 pounds of force. However, his confusion was dispelled when he thought of the book resting on the spring.

S: Alright I'm having trouble with this one because I'm thinking in terms of they both should exert force on, forces on each other because B has to readjust itself, it has to readjust from that stress, it has to relieve that 200 pound stress. However, it only weighs 40 pounds. Because of that number, um, I don't know whether it can do that.

S: Um, does B exert an upward force on A. Makes some sense to me. The reason it doesn't make perfect sense to me is because block A is so much more heavier than the other. Wait a minute...I, I'll have to change that, well I don't know if I can, but put it this way, I've just thought about the instances of the book and the spring and of course the spring was, weighed so much less than the book but still the spring did boun, the spring did bounce back. Those atoms are still springy. What happened is that, you evil people, these boxes, when I look at them, are very deceiving. One looks so much bigger than the other, that one is unsure that hey will B be able to exert that upward force, but of course it does. Even if one weighs, even if one weighs so much more than the other because sure, the book weighed so much more than the spring, but the spring did bounce, the spring bounded back, why can't the same thing happen to this?

CONCLUSIONS AND IMPLICATIONS FOR TEACHING

To return to an epistemological point, learning must be viewed as the interaction of sensory experiences and previously existing conceptions. Although the sample in this study is small, the results encourage us to believe that a serious effort to take existing student conceptions into account, both positive anchors as well as negative misconceptions, may reap significant educational benefits. The results of this study indicate that it is possible in some cases to alter student beliefs with carefully chosen thought situations, without the benefit of additional empirical experience, when students' positive anchoring intuitions are extended to target problems involving misconceptions. In saying this, we do not mean to downplay the importance of empirical evidence and concrete experiences in learning science, but we do wish to highlight the important role that can be played by thought situations as well.

However, the results also indicate that different methods of using thought situations may be less effective than others. For the book on the table (target) post question, all seven students receiving the experimental explanation expressed a confident belief in an upward force from the table, whereas of the seven receiving the control explanation, five refused to accept the conclusion of an upward force, even though the latter explanation had given the correct answer to this problem explicitly. There were also significant differences in performance on the other (transfer) post questions in favor of the experimental explanation, providing further evidence that the experimental subjects' understanding of the concept was superior.

The traditional use of thought situations, exemplified by the control explanation, is to treat them as examples of an abstract principle demonstrating the types of situations to which that principle applies. However, this study indicates that this approach may be ineffective when the student holds a misconception. The performance of the control students on the post target and transfer problems was quite low. This indicates that there was not a successful process of induction for generating or confirming an abstract schema in a form that could be applied to the post problems. Examination of protocol evidence from the current study indicates three possible reasons for the observed differences in student response to the two explanations.

1) Some of the individual examples in the control explanation were counter-intuitive to many students (e.g. the runner and the stone). However, most examples in the experimental explanation tended to make sense to the students. In particular, all students said that the anchoring example of the hand pushing on the spring made sense to them intuitively.

2) In some cases examples in the control explanation made sense to the students by tapping their intuition (e.g. the rifle kick), but students could not see an analogical connection to the book on the table situation. However, the experimental explanation put an emphasis on developing such connections by presenting the analogous cases as an ordered chain of connected examples.

3) Helping the student construct a mechanistic (i.e. causal) model of a situation evoking a misconception can be an important step in helping a

student change his or her conception of the situation. Some students may even require a mechanistic model which makes sense to them before they will change their conception of a situation.

In conclusion, the present study indicates that the use of thought situations can be an effective means for bringing about conceptual change and growth in students. Further, if the results of this study are confirmed, this means that the particular method one uses in example-based teaching can be crucial to learning outcomes. Teachers need to be aware that certain examples they themselves find compelling may not be at all illuminating for the student. Even when the example is compelling to the student, it may not be seen as analogous to the target problem in the lesson. Such analogical connections of qualitative similarity are not always obvious, and may require attention in instruction through techniques such as bridging. Finally, teachers need to keep in mind the goal of helping students develop visualizable, qualitative models of physical phenomena.

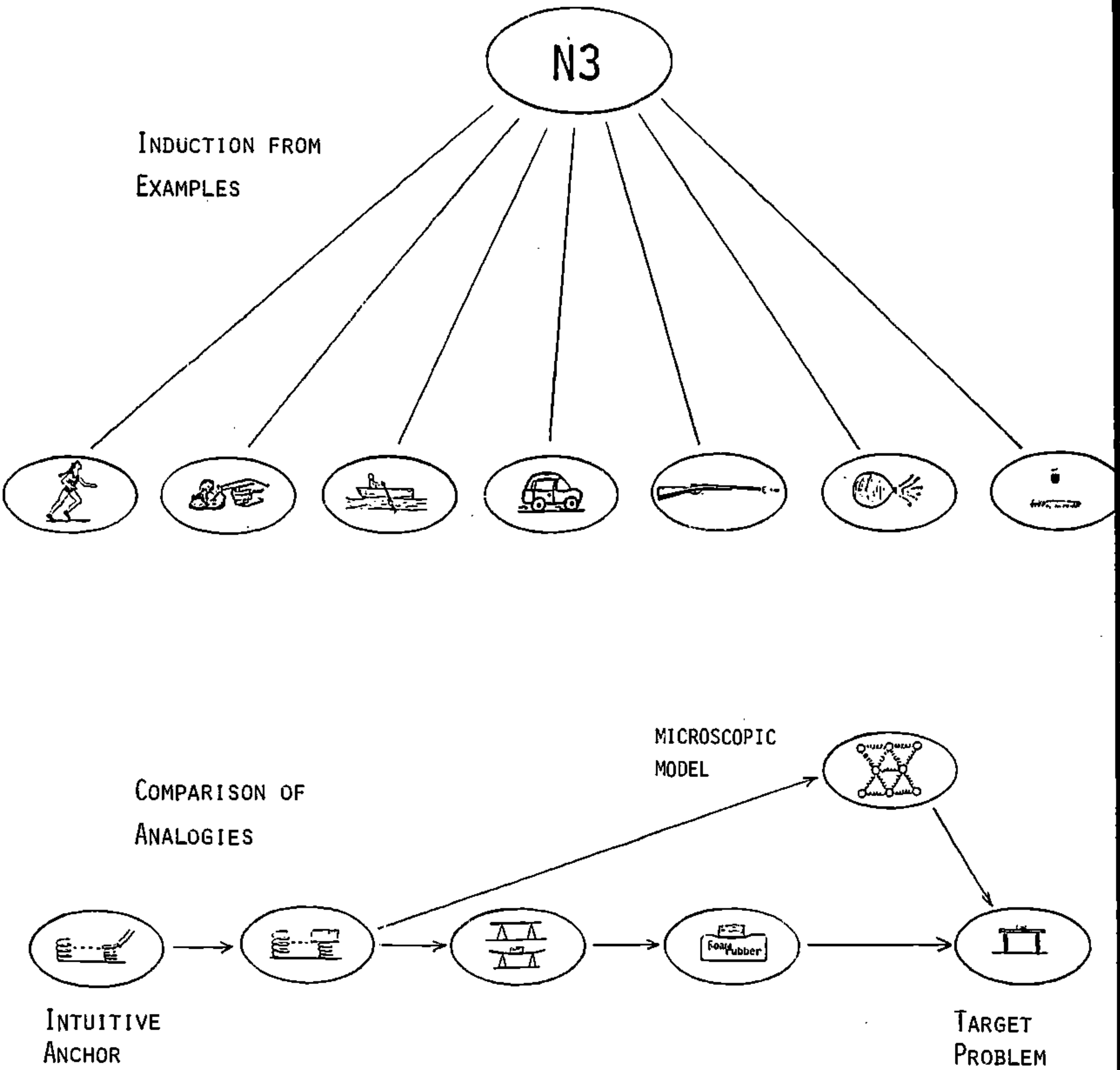
N3
INDUCTION FROM EXAMPLES
MICROSCOPIC MODEL
COMPARISON OF ANALOGIES
Foam Rubber
INTUITIVE ANCHOR
TARGET PROBLEM

FIGURE 1

NOTES

1) Rutherford, F. J., Holton, G., & Watson, F. G. (Eds.) (1981). Project Physics Text. United States of America: Project Physics.

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APPENDICES

I. The two explanations.

II. The five questions, three of which were used as both pre and post questions.

III. The page explaining the sense scale.

[Control Explanation]

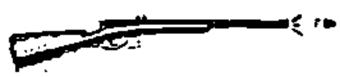
In this exercise we will consider the question of whether a table pushes up on a book resting on it. Newton's third law says that the table does exert a force on the book. Newton's third law states: To every action there is always opposed an equal reaction: or, mutual actions of two bodies upon each other are always equal and directed to contrary parts. This is a word-for-word translation from <u>the Principia</u>. In modern usage, however, we would use <u>force</u> where Newton used the Latin word for action. So we could rewrite this passage as follows: If one object exerts a force on another, then the second also exerts a force on the first; these forces are equal in magnitude and opposite in direction.

Apply this idea to an athlete running. You now see that her act of pushing with her feet back against the ground (call it the <u>action</u>) also involves a push of the ground forward on her (call it the <u>reaction</u>). It is this reaction that propels her forward.

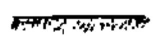
In this and all other cases, it really makes no difference which force you call the action and which the reaction, because they occur at exactly the same time. The action does not "cause" the reaction. If the earth could not "push back" on her feet, the athlete could not push on the earth in the first place. Instead, she would slide around as on slippery ice. Action and reaction coexist. You cannot have one without the other. Most important, the two forces are not acting on the same body. In a way, they are like debt and credit. One is impossible without the other; they are equally large but of opposite sign, and they happen to two different objects.

Newton wrote: "Whatever draws or presses another is as much drawn or pressed by that other. If you press a stone with your finger, the finger is also pressed by the stone." This statement suggests that forces always arise as a result of mutual actions ("interactions") between objects. If object A pushes or pulls on B, then at the same time object B pushes or pulls with precisely equal force on A. These paired pulls and pushes are always equal in magnitude, opposite in direction, <u>and on two different objects</u>.

Every day you see hundreds of examples of this law at work. A boat is propelled by the water that pushes forward on the oar while the oar pushes back on the water. A car is set in motion by the push of the ground on the tires as they push back on the ground; when friction is not sufficient, the push on the tires cannot start the car forward.



While accelerating a bullet forward, a rifle experiences recoil, or "kick." A balloon shoots forward while the air spurts out from it in the opposite direction. Many such effects are not easily observed. For example, when an apple falls, pulled down by its attraction to the earth, i.e., by its weight, the earth, in turn, accelerates upward slightly, pulled up by the attraction of the earth to the apple.

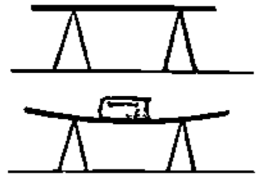


To summarize, many people say the table is not exerting a force upward on the book. However, the book is exerting a force downward on the table because of its weight. Therefore, because of Newton's third law, the table is exerting an equal force upward on the book.

In this exercise we will consider the question of whether a table pushes up on a book resting on it. Consider pushing down on a spring with your hand.

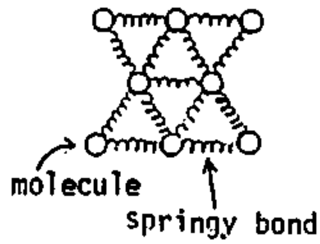
Now consider the case of a heavy dictionary being placed on a bedspring so the spring compresses some.

When the book is placed on the spring, the spring compresses. The further down the spring is pushed, the more it pushes back. The spring is compressed by the book to the point where it pushes back with a force equal to the book's weight. For example, if the book weighs 10 pounds, the spring compresses until it exerts an equal upward force of 10 pounds. In a similar way, if you hold a 30 pound dictionary in your outstretched hand, you have to exert an upward force of 30 pounds to hold it there.



Many people say the book on the spring is different than the book on the table. They say that although neither is alive, the spring compresses but the table is rigid. But is the table rigid? Imagine a flexible board between two sawhorses. If you were to push down on this board it would bend and push back, just like pushing down on the spring. The board would also push back on a book, just like the spring. Now imagine thicker and thicker boards.

If you had a thick enough board, it would be just like a table. Both the board and the table would bend a tiny, tiny bit under the weight of a book. Another way to think of the table is like very stiff foam rubber. Even though the stiff foam rubber would not compress much under the weight of a book, it would compress some.

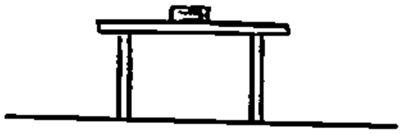


The table is composed of molecules which are connected to other molecules by bonds which are "springy." Thus the table has some amount of give or "bendiness" or "squishiness" to it. If you were to look closely with a microscope you would see that the book causes a slight depression in the table. The table, just like the spring, the flexible board, or foam rubber, is bent or compressed some and thus pushes back. Like the spring holding the dictionary, the table bends or compresses just enough to provide an upward force equal to the book's weight.

To summarize, many people do not think the table can exert a force since it is rigid and lifeless. However they feel a spring can exert a force if a force is exerted on it because it "wants to get back to its original shape." Thus there seems to be a distinction between rigid objects and springy objects. However, if you look closely enough at a table it <u>is</u> springy because of its molecular makeup. Because of this springy nature of <u>all</u> matter, the table can and does exert a force upward on the book. Just like a spring, the table compresses (on a microscopic scale) until it is compressed enough to provide an upward force equal to the book's weight.

TABLE PROBLEM

A book is at rest on a table.



Which of the following do you think is true?

___The table exerts a force upward on the book.

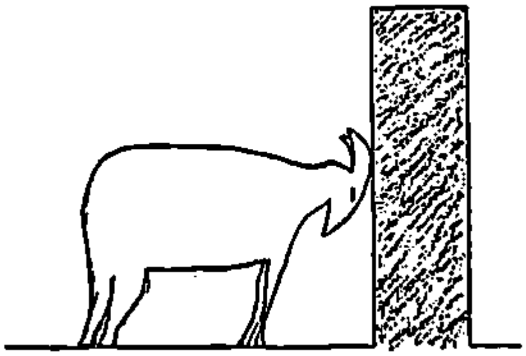
___The table does not exert an upward force on the book.

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

Please explain why you think the table exerts or does not exert a force up on the book.

GOAT PROBLEM

A stubborn goat is pushing against a wall.



While the goat is pushing, does the wall exert a force back on the goat?

___1) Yes

___2) No

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

If you said yes:

___A) The wall exerts a force back on the goat which is larger than the goat's force on the wall.

___B) The wall exerts a force back on the goat which is smaller than the goat's force on the wall.

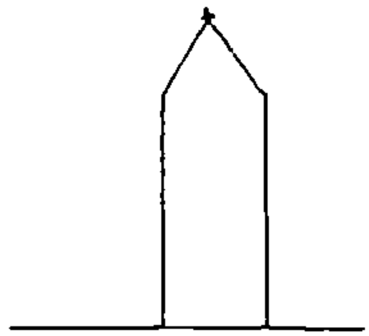
___C) The wall exerts a force back on the goat which is the same size as the goat's force on the wall.

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

MOSQUITO PROBLEM

On a day with no wind, a mosquito lands on top of the Washington Monument.

Think about whether the mosquito exerts a force on the monument and whether the monument exerts a force on the mosquito while it is resting there.



While the mosquito is resting there, does the monument exert an upward force on the mosquito?

___1) Yes

___2) No

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

If you said <u>yes</u>:

___A) The monument and the mosquito each exert a force on the other, but the mosquito exerts a larger force.

___B) Each exerts a force, but the monument exerts a larger force.

___C) Each exerts a force, and the forces are the same size.

___D) Only the monument is exerting a force.

If you said <u>no</u>:

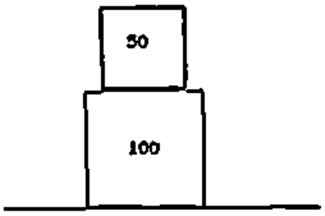
___E) The mosquito exerts a force on the monument.

___F) The mosquito does not exert a force on the monument.

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

TWO BOXES PROBLEM

A box weighing 50 pounds rests on top of another box weighing 100 pounds. Think about whether the upper box exerts a force on the lower box and whether the ground exerts a force on the lower box.



Does the ground exert an upward force on the lower box?

___1) Yes

___2) No

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

If you said yes:

___A) Both the ground and the upper box exert forces on the lower box, but the upper box exerts the larger force.

___B) Both the ground and the upper box exert forces on the lower box, but the ground exerts the larger force.

___C) Both the ground and the upper box exert forces on the lower box, and these forces are the same size.

___D) Only the ground exerts a force on the lower box.

If you said no:

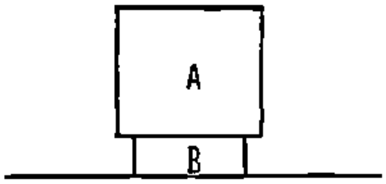
___E) The upper box exerts a force on the lower box.

___F) The upper box does not exert a force on the lower box

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

STEEL BLOCKS PROBLEM

A large steel block weighing 200 lbs. rests on a small steel block weighing 40 lbs. as shown below. Think about whether A exerts a force on B and whether B exerts a force on A.



Does B exert an upward force on A?

___1) Yes

___2) No

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

If you said yes:

___A) A and B each exert a force on the other, but A exerts a larger force.

___B) Each exerts a force, but B exerts a larger force.

___C) Each exerts a force, and these forces are the same size.

___D) Only block B exerts a force.

If you said no:

___E) Block A exerts a force on block B.

___F) Block A does not exert a force on block B.

I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

Appendix III

WHAT MAKES SENSE?

Throughout our lives, we have had a wealth of experience with the physical world which leads us to feel that some things make sense and other things don't. A statement makes sense when we understand it at an intuitive or "gut" level.

There are times when we know an answer is correct, (that is we are very confident in our answer) but it doesn't really make sense. For example, many people are confident that if a person throws a boomerang, it will circle around and come back. But it doesn't make sense to them that it should come back. What makes sense to them is that the boomerang should just go in a straight line.

At other times, we are confident about an answer, and it makes perfect sense. For example, if a large truck runs into a small car, most people are confident that the car will get damaged. It also makes sense to them that the car would be damaged.

For the question the interviewer shows you, please rate how much sense each answer makes using the scale below. (Note: When you give your ratings, please rate how much sense each answer makes, not how confident you are that the answer is correct.)

1	2	3	4	5
Makes no sense to me	Makes only a little sense to me	Makes some sense to me	Makes quite a bit of sense to me	Makes perfect sense to me