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ABSTRACT

Three purposes of this study were to: (1) propose some organizing theoretical and observational definitions of the anchor construct; (2) present some initial findings from a diagnostic test designed to uncover anchors for high school physics instruction; and (3) provoke an initial discussion of the new methodological issues that arise in this domain. The results of the diagnostic test indicate that a number of group anchors exist, such as the belief that a spring pushes up on a hand compressing it. Second, unexpected non-anchors, for example, the belief that a stationary railroad box car does not exert a force on a man travelling on the front of a second box car which runs into the stationary car, are discussed. Third, evidence was found that some anchoring examples were "brittle," that is, evidence that the anchor could not be extended analogically to help a student make sense of a target situation. It was suggested that further research is needed to construct a theory of anchoring conceptions that would specify what characteristics would indicate that an anchoring conception can provide the basis for conceptual change through analogical extension. The diagnostic test items and the anchor diagnostic results are provided. (YP)

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NOT ALL PRECONCEPTIONS ARE MISCONCEPTIONS: FINDING "ANCHORING CONCEPTIONS" FOR GROUNDING INSTRUCTION ON STUDENTS' INTUITIONS

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Abstract. This study begins the task of mapping out the domain of valid, potentially helpful beliefs of students and raises the possibility of drawing on these intuitions in teaching conceptual material. Some issues surrounding the identification of such intuitions, referred to as anchoring conceptions or anchors, are explored. We attempt to: (1) define the concept of an anchor both in terms of an internal knowledge structure and in terms of an observable response to diagnostic test questions; and (2) define the concept of an anchoring example for an individual student as well as for a group of individuals.

The results of the diagnostic test indicate that a number of group anchors exist, such as the belief that a spring pushes up on a hand compressing it. Second, unexpected non-anchors, e.g. the belief that a stationary railroad box car does not a exert a force on a man travelling on the front of a second box car which runs into the stationary car, are discussed. Third, we found evidence that some anchoring examples were "brittle", i.e. evidence that the anchor could not be extended analogically to help a student make sense of a target situation.

Finally, it is suggested that further research is needed to construct a theory of anchoring conceptions, which would for example, specify what characteristics would indicate that an anchoring conception can provide the basis for conceptual change via analogical extension.

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Introduction

It is now well established that students' preconceptions (ideas held before instruction) often pose strong barriers to understanding in physics. Although many preconceptions are detrimental to learning, there may be other preconceptions which are largely in agreement with accepted physical theory. These will be referred to here as "anchoring conceptions" (or more briefly, as anchors). This study focuses on the possibility of identifying such positive intuitions and explores some of the issues surrounding their potential for use in instruction.

We assume that it is desirable to be able to ground new material in that portion of the student's intuition which is in agreement with accepted theory. When this is possible, it should help students to understand and believe physical principles at a "makes sense" level instead of only at a more formal level. For example, many students refuse to believe that static objects can exert forces. They refuse to believe the physicist's assertion that a table exerts a force on a coffee cup sitting on the table. However, almost all students believe that a spring will exert a constant force on one's hand as one holds it compressed. In teaching that inanimate objects can exert forces, this intuition about springs can be built on as an anchor. By working with students to help them see that even "rigid" objects are springy to some extent, one can anchor the idea of static forces in the student's intuitive conception of springiness.

In this paper we will use the term misconception to refer to students' ideas which are incompatible with currently accepted scientific knowledge. To be sure, misconceptions should be respected as creative constructions of the individual. In some cases misconceptions are also adaptive and successful for dealing with the practical world. They do, however, present significant difficulties in learning a subject like Newtonian mechanics. In these terms, our first hypothesis is that not all preconceptions are misconceptions; rather, some of the students' preconceptions are useable anchoring conceptions.

While considerable research has been conducted on misconceptions in science, very little is known about anchoring conceptions. Three purposes of this study are to: (1) propose some organizing theoretical and observational definitions of the anchor construct; (2) present some initial findings from a diagnostic test designed to uncover anchors for physics instruction; and (3) provoke an initial discussion of the new methodological issues that arise in this domain.

Anchoring Examples and Anchoring Conceptions

Defining the concept of an anchor involves a number of theoretical and methodological issues. First, how should we define an anchor in terms of internal knowledge structures? In theoretical terms we define an _anchoring conception_ as an intuitive knowledge structure which is in rough agreement with accepted physical theory. By intuitive, we mean in particular that it is self evaluated--the strength of the belief is determined by the subjects themselves rather than by appeal to authority. (See Clement (to appear) for an expanded discussion of elemental physical intuitions as knowledge structures.)

At the observational level we have found the following definition to be useful: a problem situation is an anchoring example for a student if he or she makes a correct response to the problem and indicates substantial confidence in the answer (defined here as a confidence level greater than or equal to two on the confidence scale used in the problems in Appendix I) (Note 1). An observed anchoring example, then, provides one source of evidence for detecting an anchoring conception in the mind of the student, especially when there is reason to believe that the student's answer was not simply memorized by rote.

Second, data from diagnostic tests can indicate that a particular example is an anchoring example for a group as well as for a particular student. We refer to a problem situation as a 'group anchor' for a sample of students if it is an anchoring example for a certain criterion percentage of those students (this percentage is termed the "belief score" for that group). Thus in this study the belief score is the percentage of students who answered the problem correctly with a confidence level of 2 or higher. In using anchors in experimental lessons in introductory physics over the last few years, our experience is that if an example is a confident anchor on a pretest for about 70% of the students in a sample, most other students will indicate that the idea makes sense to them after a minimal amount of instruction, such as a demonstration. Thus we have considered problems with a belief score of 70% or higher to be group anchors that have excellent potential for use in instruction. This criterion is somewhat arbitrary and was determined by practical considerations in searching for examples that will be useful in instruction.

Results from an Anchor Diagnostic Test

Method. The diagnostic test in Appendix I was administered in three Western Massachusetts high schools to students who had not yet taken physics and who were enrolled in chemistry or biology courses (the courses from which virtually all students who elect to take physics are drawn in these schools). The test consists of three questions designed to elicit common misconceptions followed by 15 questions designed to identify anchoring examples. The questions included both static and dynamic situations involving forces and their effects. They were generated in brainstorming sessions with researchers and high school physics teachers while attempting to design experimental lessons. (Lessons are discussed in Clement, et al., 1987). The instructions on the first page were explained, and students were asked to rate each of their answers on the confidence scale appearing in the problems. In addition, clinical interviews were conducted with five students after they had taken the test.

Results

Group anchors. A number of group anchors were discovered as indicated by the results in column 4 of Appendix II. For example, 80% answered correctly with high confidence that a spring pushes up on your hand when you press down on the spring and hold your hand still. Eighty four percent answered with high confidence that a rowboat would move to the left when a person stepped out of it to the right. Seventy four percent answered with high confidence that a skater pushing another skater to the right would herself move to the left (although not necessarily at the same speed, even though the skaters are the same weight). Given that two carts on a smooth floor are pushed apart by a spring not attached to either cart, 83% of the students were confident that the carts would move apart at the same speed. Finally, students were also very confident that two people of the same height holding the ends of a light board on which a 100 pound block is resting, would "feel the same amount of weight" (76% th high confidence), although only 55% were very confident that this "same amount of weight" would be 50 pounds for each person.

Unexpected results. There were also some unexpected results. Some examples that we expected to be group anchors were found not to be confident anchors. For example, only 22% answered with confidence that a wall exerts a force on your fist when you punch the wall, an example often used in attempts to convince students that static objects such as walls can exert forces. Fifty nine percent indicated the wall does not exert a force on your fist, and 36% gave this answer with high confidence.

There were also some cases in which we expected certain anchors to be stronger than others. For example, given the situation of a hand pushing down on a spring, students were asked whether the spring exerts a force on the hand. This was considered to be a good candidate for an anchor, but we had some reservations about how strong an anchoring example it would be. We expected that the upward force would be more intuitive in the case of holding up a thirty pound dictionary on an outstretched hand. In both cases the subject can imagine feel ng the upward force, but the dictionary situation involves a person exerting the force and allows for direct use of kinesthetic intuition. However, the results indicated that the hand-on-spring situation was in fact an anchoring example for more students (belief score of 80%) than the dictionary-on-hand situation (belief score of 65%). One possible reason for the spring being a stronger anchor is that the spring moves up when the hand is removed, whereas this is not so obvious for the hand when the book is removed.

Perhaps the most surprising result from this study was the low belief score for the log exerting a force on Mr. T's chest in question 5. We predicted this situation would be a solid anchor for students because of the opportunity to identify with a person in the problem. However, this situation was an anchor for only 53% of the students. A full 30% answered, although some with low confidence, that the log would not exert a force. In the interviews students were aware that Mr. T would be hurt; however, this did not necessarily mean that they believed the log exerted force. One student said he felt sorry for Mr. T even though he answered the log exerts no force. We are interested in using deeper probes and analysis techniques to determine the origins of these anomalous responses in the future.

Instructional Applications and the Problem of Brittle Anchors

Teaching strategies. Clement, et. al. (1987) report success in using an approach to overcoming misconceptions in mechanics which uses anchors as a central element in the teaching strategy. The hand on the spring situation, for example, is used as an anchoring example for helping students make sense of the idea that static objects can exert forces. (The target problem in this case was whether a table pushes up on a book.) The approach also involves the use of "bridging analogies" such as a book on a foam pad or a book on a thin flexible board. Engaging students in socratic discussion of these intermediate bridging cases is designed to help the student see that the rigid table can be thought of as flexible and spring-like. They help the student transfer a central idea from the anchor--the idea of "applied force causing deformation causing a reaction force", thereby providing a mechanism for the reaction force.

This causal relationship of applied force causing deformation causing a reaction force is an example of what we call the "key relationship" or "key structure"--the major relationship in the situation that we wish the student to transfer to other situations. Sometimes this can also be accomplished via a transformation--if the student believes that the flexible board pushes up on the book, and sees that the board can be gradually transformed into the more rigid table by making it thicker and thicker, he may come to believe that the table pushes up as well. Thus anchors have been used successfully in instruction.

In some cases, however, pilot tutoring has indicated that the strategy of using analogies with anchors can fail. For some anchoring examples, even though students are in complete agreement with the physicist in their predictions about the anchor situation, they refuse to believe that the prediction applies to the target situation. Apparently they cannot transfer the key relationship to the target in such cases. In such a case we refer to the anchor as "brittle".

Brittle anchors. The results of the studies also suggest the possibility of "brittle" anchors, especially for beliefs based on symmetry. As an example of what we mean by "brittleness," 96% of the students in one test answered correctly that identical carts, pushed apart by a spring suspended between the carts, would move apart at the same speed. However, only 32% said they would move apart at the same speed for the almost identical, but asymmetrical situation in which the spring was attached to one of the carts. The two problems were back-to-back, suggesting that a majority of students saw the minor change (attaching the spring to one cart) as significant. Hence, the symmetrical carts situation may be a brittle anchoring example, in which a small modification changes the students' intuitions about it.

As another example, 97% of the students answered correctly that skaters of equal mass would separate with the same speed if both skaters pushed. Yet only 41% indicated that they would separate at equal speeds if only one of the skaters pushed on the chest of the other. The key relationship of equal speeds was not predicted in the second problem. Thus, we may not be able to analogically extend anchoring examples such as the symmetrical skaters or symmetrical carts situations in attempts to help students overcome the misconception represented in the asymmetrical skaters problem.

In effect, this means that anchors exist at two levels. At the first level, naive students may agree on the correct answer to a particular example. But this does not guarantee that they have in mind a useable anchoring conception. A second level is reached only when the anchoring example triggers a conception that is an extendable starting point for the physicist's conception.

In observational terms we will say that an anchoring example is brittle for a particular student if it cannot be analogically extended to help the student make sense of the target by techniques such as bridging. We interpret this phenomenon as follows. An anchoring example is brittle when:

1) It contains a feature or aspect (such as symmetry) which must be altered in order to analogically extend the anchor to the target.

2) The student considers this aspect to be critical in the following sense: if the situation is changed so that the aspect is altered, the student no longer believes that the key relationship or predicted outcome is valid, even though it is still valid from the physicists' point of view. Even if one attempts to gradually transform the critical feature by small degrees via a bridging strategy, the student resists transferring ideas from the anchoring situation to the target situation.

Thus, since the student views altering a critical feature (e.g. symmetry) as destroying the key relationship and the predicted outcome, the anchor is brittle. Changing the critical feature changes the students' conception of the situation, and the change cannot be made less critical by instructional techniques such as bridging.

A requirement for a bridging approach is that one can always "split the difference" with a conceptually intermediate situation. Metaphorically, this requires a conceptual domain analogous to the real number line, where between any two reals one can always find another real. Thus one would expect to find brittle anchors in conceptual domains analogous to a discrete number line. For example, just as between 1 and 2 there exists no whole number, between symmetry and lack of symmetry there exists no intermediate state.

The potential brittleness of symmetrical anchors becomes important in attempts to develop a more principled way of generating anchoring examples. As shown in Table 1, every one of the five symmetric situations in the diagnostic was an anchoring example, with the exception of the colliding billiard balls, which came within one percentage point (belief score = 69%). Thus, although one could reliably predict that most students will answer correctly for symmetrical situations, these examples may be of little use in a teaching via analogy approach since, for many students, the key elements of the situation will no longer be present once the symmetry is broken. (See Brown and Clement (1989) for an analysis of a protocol involving a brittle anchor.)

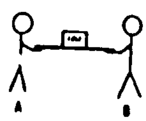
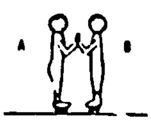
Concluding Comments

Critique. It is likely that scores from an anchor diagnostic given at the beginning of a physics course may in some cases be misleading later in the year. We have the impression from classroom observations that group anchor

Table 1
Symmetry Anchors

Total population
N = 137

ONLY THE SCORES FOR CORRECT ANSWERS ARE GIVEN.

Problem	Answer	Belief Score
carts 	(a) A moves left (b) B moves right (c) same speed	.75 .77 83
board 	(a) same weight felt (b) weight: 50lbs	.76 .55
skaters 	(a) A moves left (b) B moves right (c) same speed	.77 .75 83
carts 	(a) A moves left (b) B moves right (c) same speed	.72 .74 .79
billiard balls balls 	(a) forces are equal	.69

scores may rise during the year even when they have not had direct practice on the test questions. Experiences in the laboratory and related topics in the course may produce this effect Thus, the most appropriate time to test for anchors may be just before beginning a unit in which an anchor is needed.

Also, it should be noted that even when only 30% of the students believe an anchor with high confidence, it is still an anchor for those students, and therefore may be useful in instruction for them. This suggests that the use of multiple anchors in the classroom or individualized anchors in computer courseware may be able to reach different students in different ways. (See Murray, Schultz, Brown, and Clement, 1987 for a description of a computerized teaching program which uses different anchors and bridges for different students.)

In addition, very short instructional interventions may in some cases raise belief scores significantly from say, 55% to 80%. If this is true, such examples which were not group anchors on a diagnostic test could still be used effectively in instruction. These are interesting issues for future research.

Implications. In conclusion, we have described some initial attempts to systematically map out the domain of positive, potentially helpful preconceptions. These results, in combination with numerous studies conducted on students' alternative conceptions, strongly indicate that physics students cannot be considered "blank slates." Fortunately, some of the students' prior knowledge can be helpful to learning if anchoring conceptions can be tapped and used appropriately (Brown, 1987; Clement et al., 1987). The situations that were predicted to be anchors, but that turned out not to be, indicate that examples which teachers take for granted as "obvious" and helpful may be seen in a very different way by students. Research is required to determine whether the base-level examples used in lessons make sense to students.

Teachers can contribute to this research task by collecting data on diagnostic questions in the classroom, or more informally, by having students vote in class on whether examples make sense to them. With this kind of feedback, teachers should be able to find more effective anchoring examples.

Although we have proposed some initial organizing theoretical and observational definitions, further research is needed to specify a theory of anchoring conceptions. Such a theory would attempt to answer at least two questions: 1) what are the characteristics of a strong anchoring conception (perhaps related to the origins of physical intuition), and 2) what characteristics indicate that an anchoring conception can provide the basis for conceptual change via analogical extension?

Acknowledgements

We wish to thank Marge Coahran for providing an initial analysis of our data and for her important contributions to the early phases of this project, and Clifford Konold for his helpful comments on the manuscript.

Notes

1. Perhaps they should actually be called "potential anchors." As will be shown, not all anchoring examples defined in this way can be used effectively in instruction via transfer. Thus in some contexts it may be useful to split the concept of anchoring example as follows: potential anchors are anchoring examples defined as above; useable anchors are anchoring examples which can l extended in instruction so that the useful conception is transferred to other more difficult examples.

Also it should be noted that in using a multiple choice test alone there is no guarantee that students answering correctly have the same anchoring conception in mind as the experimenter.

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APPENDIX I

INSTRUCTIONS FOR SCIENCE DIAGNOSTIC

Name____________________

Instructor____________________

This diagnostic is a series of questions about a number of real life situations. For these questions:

1) Don't spend too much time on each question, but
2) Please mark the answer you honestly think is right.

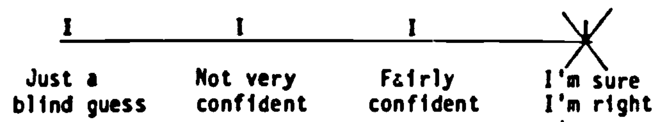
The diagnostic will not affect your grades. But we do ask that you take it seriously since we will be using the results to try to improve science courses.

On each question you will be asked to say how sure you are of your answer. For instance, if the question were:

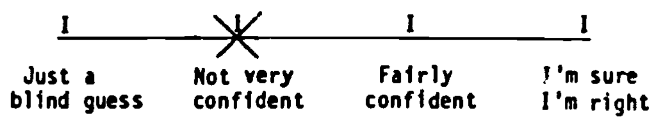
When you drop a silver dollar, it will:

__(a) fall to the ground
__(b) rise into the sky
__(c) float in midair

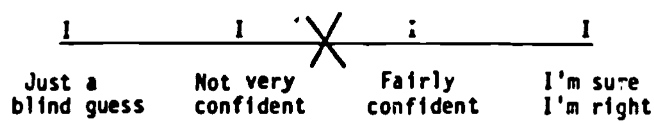
You would probably mark (a) and be absolutely sure. In this case you would mark the confidence scale like this:



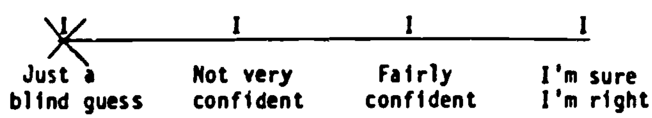
However, if you weren't too sure, you might mark:



or



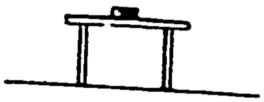
If you have no idea about a question, take a guess and mark



Thank you!

(1) 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.

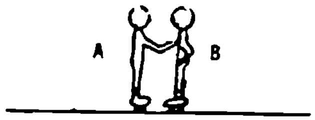
___The table does not exert an upward force on the book.

I ________ I ________ I ________ I

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

(2) SKATERS PROBLEM

Two roller skaters are facing each other standing still. The floor is very smooth and both skaters can roll easily. Both roller skaters hold their skates straight, so both are free to roll forward or backward.



Please answer the following three questions for the case when A pushes on B's chest and does not hold on. A and B have the same weight.

I think: (Mark one)

a)___A moves to the right (⟶)
___A moves to the left (⟵)
___A remains stationary

I ________ I ________ I ________ I

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

b)___B moves to the right (⟶) (Mark one)
___B moves to the left (⟵)
___B remains stationary

I ________ I ________ I ________ I

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

c)___A moves faster (Mark one)
___B moves faster
___Both move at the same speed

I ________ I ________ I ________ I

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

(3) SHUFFLEBOARD PUCK PROBLEM

You slide a shuffleboard puck on the floor, and eventually it comes to a stop.

While it is moving, which of the following do you think is true?

___The floor exerts a force on the puck in the same direction the puck is moving.

___The floor exerts a force on the puck in a direction opposite to the puck's motion.

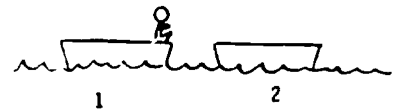
___There is a force from the floor which affects the puck's motion, but it is not in any particular direction.

___The floor does not exert a force on the puck which affects its motion.

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

(4) ROWBOAT PROBLEM

Two small boats float freely on a perfectly calm pond. They are three feet apart.



When Suzie jumps from boat 1 into boat 2, boat 1 will

___Move to the right

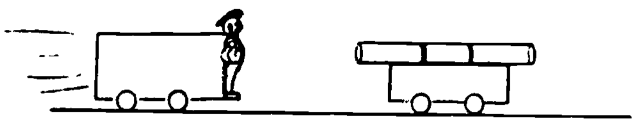
___Move to the left

___Remain stationary

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

(5) LOG PROBLEM

Mr. T rides on the front of a runaway boxcar which then runs into a stationary car carrying a single large log. Mr. T's chest meets the log head on, starting the log car in motion.



During the collision the log

___Exerts a force on Mr. T's chest.

___Exerts no force on Mr. T's chest.

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

(6) LOG PROBLEM II

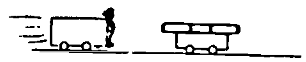
An insane criminal has captured Mr. T and gives him a choice - he can be on the moving boxcar in drawing 1, or he can be on the stationary boxcar in drawing 2.

In words, the two situations are:

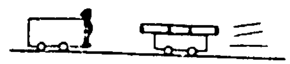
1) The boxcar (moving at 20 mph) hits the stationary log car, starting the log car in motion.

2) The log car, (moving at 20 mph) hits the stationary boxcar, starting the boxcar in motion.

** In both situations, Mr. T's chest meets the log head on. Both cars are free to roll, and both weigh one ton.



1



2

Mr. T's chest would:

___Feel more force in situation 1.

___Feel more force in situation 2.

___Feel the same force in both situations.

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

(7) DICTIONARY PROBLEM

When you hold a very heavy 30 pound dictionary perfectly still in your hand, gravity exerts a downward force of 30 pounds on the dictionary.

When holding it perfectly still, your hand

___Pushes up on the dictionary.

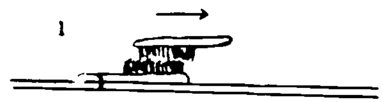
___Does not push up on the dictionary.

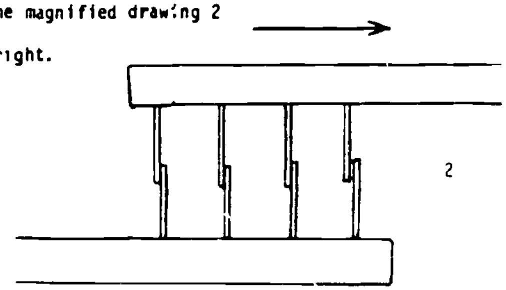
I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

(8) HAIRBRUSH PROBLEM

You have two identical hair brushes shown in drawing 1 below. You clamp one down tightly on a table, and pull the other one across it so that the bristles mesh. The bristles bump and bend each other as shown in the magnified drawing 2 below. You pull the top brush to the right.

1





2

Does the <u>upper</u> brush exert a force on the <u>lower</u> brush?

___No.

___Yes, it exerts some force to the right on the lower brush.

___Yes, it exerts some force to the left on the lower brush.

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

Does the <u>lower</u> brush exert a force on the <u>upper</u> brush?

___No.

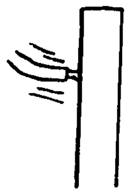
___Yes, it exerts some force to the right on the upper brush.

___Yes, it exerts some force to the left on the upper brush.

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

(9) FIST PROBLEM

You hit a brick wall as hard as you can with your fist.



When your fist hits the wall

___The wall exerts a force on your fist.

___The wall does <u>not</u> exert a force on your fist. The wall is just in the way.

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

(10) CARTS PROBLEM

Two identical carts resting on a smooth level floor are tied together by a rope. Between the two carts there is a compressed spring. The spring is not attached to either cart. The rope is cut and the spring stretches to its normal length and falls to the ground.

When the rope is cut in the middle

a) ___A moves to the right (⟶)
___A moves to the left (⟵)
___A remains stationary

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

b) ___B moves to the right (⟶)
___B moves to the left (⟵)
___B remains stationary

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

c) ___A moves faster
___B moves faster
___Both move at the same speed

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

(11) CARTS PROBLEM II

Two identical carts resting on a smooth level floor are tied together by a rope. Cart A has a spring attached to it which presses up against cart B as shown below. The spring is not attached to cart B. The rope is cut and the spring stretches to its normal length.

(Note: Because the attached spring adds a little weight to cart A, a small extra weight is added to cart B to make their weights equal aga.n.)

When the rope is cut in the middle

a)___A moves to the right (⟶)
___A moves to the left (⟵)
___A remains stationary

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

b)___B moves to the right (⟶)
___B moves to the left (⟵)
___B remains stationary

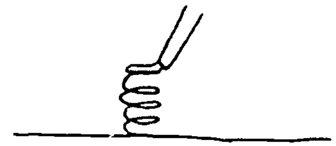
I	I	I	I
Just a blind guess	Not very confident	Fairly confident	I'm sure I'm right

c)___A moves faster
___B moves faster
___Both move at the same speed

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

(12) HAND ON SPRING PROBLEM

You push down on a bed spring with your hand. After you push the spring down 4 inches, you hold the spring down, keeping your hand still.



When holding your hand still against the pushed down spring, does the spring push back up on your hand?

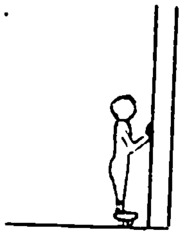
___Yes

___No

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

(13) ROLLER SKATE WALL PROBLEM

You are on roller skates and stand facing a wall. Your face is very close to the wall, and the tips of your skates are pointed forward. You then quickly extend your arms, pushing as hard as you can on the wall.



When you push on the wall you

___Move to the left and roll for a ways

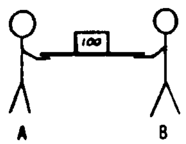
___Move to the left for a very short distance

___Stay where you are

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

(14) BOARD PROBLEM

Two people of the same height hold the ends of a light horizontal board. A 100 pound weight is resting exactly in the middle of the board.



Under these conditions

___Each person feels the same amount of weight.

___One person may feel more weight than the other.

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

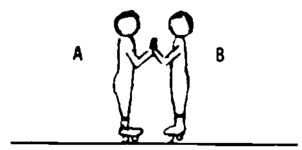
If you said each person feels the same weight, and if we don't count the weight of the very light board,

Each person feels a weight of _____ pounds.

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

(15) SKATERS PROBLEM II

Two roller skaters of equal weight and equal strength are facing each other standing still. The floor is very smooth and both skaters can roll easily. Both roller skaters hold their skates straight, so both are free to roll forward or backward.



Please answer the following three questions for the case when both push with the same effort.

a)___A moves to the right (⟶)
___A moves to the left (⟵)
___A remains stationary

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

b)___B moves to the right (⟶)
___B moves to the left (⟵)
___B remains stationary

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

c)___A moves faster
___B moves faster
___Both move at the same speed

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

(16) CARTS PROBLEM III

Two identical carts resting on a smooth level floor are tied together by a rope. Each cart has an identical spring attached to it. As shown below these springs press up against a board which is between the carts. The rope is cut and the springs stretch to their normal lengths, allowing the board to fall to the ground.

When the rope is cut in the middle

a) ___A moves to the right (⟶)
___A moves to the left (⟵)
___A remains stationary

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

b) ___B moves to the right (⟶)
___B moves to the left (⟵)
___B remains stationary

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

c) ___A moves faster
___B moves faster
___Both move at the same speed

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

(17) BILLIARD BALL FORCE PROBLEM

Two billiard balls which weigh the same move toward each other with equal speeds and collide head on.

Which of the following is true at the moment they collide?

___Each ball exerts a force on the other, and the two forces are equal in size.

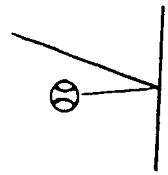
___The two balls exert forces on each other, but the forces are not necessarily equal in size.

___Neither ball exerts a force on the other.

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

(18) TENNIS BALL PROBLEM

A tennis ball hits a brick wall and bounces off.



When the ball hits the wall

___The wall exerts a force on the ball causing it to change direction.

___The wall does not exert a force on the ball. The wall is just in the way.

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

APPENDIX II

Anchor Diagnostic Results

* = correct answer

Sample: Total sample pop
n = 137

Problem Answer	Percent Answered	Average Confidence	Std. Dev. Confidence	Belief Score
1)Table				
* force up	24%	2.1	.58	.19
no force up	75%	2.3	.67	.62
2)Skaters				
A right	7%	2.0	.73	.04
* A left	83%	2.4	.57	.74
A stationery	9%	2.0	.81	.07
B right	91%	2.4	.64	.77
B left	3%	1.8	.52	.02
B stationery	5%	1.9	.24	.04
A faster	27%	1.9	.56	.18
B faster	30%	2.0	.68	.20
* same speed	41%	2.0	.72	.31
3)Shuf. Puck				
same direction	2%	1.7	.23	.01
* opp. direction	22%	1.7	.75	.09
no part. direction	36%	1.8	.71	.20
no force	39%	1.9	.74	..23
4)Rowboat				
move right	7%	2.6	.55	.06
* move left	91%	2.6	.54	.84
stationery	3%	1.6	.48	.01
5)Log				
* exerts force	70%	2.2	.73	.53
no force	30%	1.7	.78	.17
6) Log 11				
more force situation 1	8%	1.5	.68	.04
more force situation 2	38%	1.8	.67	.22
* same force	53%	2.0	.69	.43
7)Dictionary				
* force up	80%	2.3	.64	.65
no force	20%	1.9	.62	.14
8)Hairbrush				
upper brush				
no force	3%	1.1	1.4	.01
* force right	85%	1.9	.77	.50
force left	12%	1.9	.66	.08
lower brush				
no force	42%	1.7	.80	.23
force right	13%	1.2	.83	.04
* force left	44%	1.8	.75	.21

Problem Answer	Percent Answered	Average Confidence	Std. Dev. Confidence	Belief Score
9) Fist				
* force	40%	1.8	.77	.22
no force	59%	2.0	.76	.36
10)Carts				
A right	8%	1.5	1.0	.03
* A left	82%	2.5	.65	.75
A stationery	8%	1.8	.78	.04
* B right	87%	2.5	.69	.77
B left	6%	1.0	.71	.00
B stationery	6%	1.9	.79	.04
A faster	0%	0.0	.00	.00
B faster	2%	1.3	1.5	.01
* same speed	96%	2.4	.62	.83
11)Carts 11				
A right	5%	1.6	1.3	.03
* A left	70%	2.2	.75	.55
A stationery	23%	1.7	.79	.13
* B right	86%	2.3	.74	.69
B left	5%	.86	.77	.01
B stationery	7%	1.8	.61	.04
A faster	17%	1.7	.75	.11
B faster	50%	1.9	.77	.29
* same speed	32%	2.1	.81	.23
12)Hand on spring				
* force	93%	2.4	.61	.80
no force	7%	2.1	.77	.04
13)Rollerskate-Wall				
* roll a ways	75%	2.4	.71	.64
short distance	21%	2.0	.84	.14
stationery	2%	.67	1.2	.01
14)Board				
* same weight felt	85%	2.5	.55	.76
unequal weight	13%	2.1	.62	.09
Weight:				
100 lbs.	14%	2.1	.66	.11
55 lbs	1%	2.3	.00	.01
* 50 lbs.	82%	2.1	.84	.55
25 lbs.	2%	1.5	.71	.01
0 lbs.	1%	2.0	.00	.01
15) Skaters 11				
A moves right	3%	1.8	.85	.01
* A moves left	86%	2.6	.60	.77
A stationery	9%	1.8	.77	.05
* B moves right	84%	2.6	.61	.75
B moves left	6%	1.8	1.0	.04
B stationery	8%	2.0	.54	.06
A faster	0%	0.0	.00	.00
B faster	0%	0.0	.00	.00
same speed	97%	2.4	.58	.83

Problem Answer	Percent Answered	Average Confidence	Std. Dev. Confidence	Belief Score
16)Carts 111				
A moves right	4%	1.6	.49	.02
* A moves left	85%	2.5	.65	.72
A stationery	7%	1.7	.90	.04
* B moves right	86%	2.4	.65	.74
B moves left	4%	1.6	.49	.02
B stationery	6%	1.4	.97	.02
A faster	1%	0.0	.00	.00
B faster	1%	2.0	.00	.01
* same speed	94%	2.3	.68	.79
17)Billiard ball				
* forces equal	82%	2.3	.64	.69
forces unequal	14%	2.2	.81	.11
no forces	1%	2.0	.00	.01
18)Tennis ball				
* force	39%	2.1	.69	.27
no force	58%	2.0	.64	.36