DOCUMENT RESUME

ED 299 171 SE 049 743

AUTHOR	Brown, David E.
TITLE	Students' Concept of Force: The Importance of Understanding Newton's Third Law.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	18 Jan 88
GRANT	MDR-8470579
NOTE	23p.; Paper presented at the Annual Meeting of the American Association of Physics Teachers (Crystal City, VA, January 1988). May not reproduce well because of small print and marginal legibility on some pages.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Cognitive Structures; *Concept Formation; *Force; *Interviews; *Mechanics (Physics); *Misconceptions; Motion; Physics; Science Education; Scientific Concepts; Secondary Education; *Secondary School Science

ABSTRACT

This paper analyzes the misconceptions high school students have about force and suggests that the misunderstanding of Newton's third law is the key to these misconceptions. Clinical interview and diagnostic test data (N=104) indicates that many students have a naive view of force as an acquired or innate property of single objects rather than that of forces arising from an interaction between objects. Some students' view of objects as inherently more "force-full" by virtue of their mass, speed, or activity suggests that Newton's third law, which makes explicit the relational quality of forces, should play a more important role than is ordinarily granted in teaching. If students acquire a deep understanding of the third law, they may have less difficulty with both quantitative problems requiring the identification of forces and qualitative problems such as those drawing out the "impetus" misconception, in which many students view force as a property of a moving object causing it to move with constant velocity. (YP)

Introduction

A number of studies conducted in recent years have demonstrated a wide range of beliefs about physical phenomena which students have apparently formed on their own without the benefit of formal instruction. Particularly well documented have been student beliefs which are in contradiction with the ideas of Newtonian mechanics. For example, many students hold the belief that there is a force on or in an object in the direction of the object's motion (Viennot 1979, Sjoberg and Lie 1981, Clement 1982) when in fact no force is necessary to keep an object moving at a constant velocity. Reviews of research on students' alternative conceptions in classical mechanics are provided by Driver and Erickson (1983), McDermott (1983), McCloskey (1983), and McDermott (1984).

Most of the student errors that have been documented in Newtonian mechanics have been on questions designed to test conceptual understanding of Newton's first or second laws. Only a few (e.g. Maloney, 1984, Boyle and Maloney, 1986, and Terry and Jones, 1986) treat the Third Law. This emphasis on the first two of Newton's three laws is in keeping with the emphasis placed on the first two laws in textbooks. The ability to flexibly use the quantitative statement of the second law (the net force acting on an object is numerically equal to its mass times its acceleration) is arguably the most important ability a student can acquire for success in an introductory physics course. This preeminence of the quantitative statement of the second law in instruction is illustrated by the fact that the very popular PSSC high

STUDENTS' CONCEPT OF FORCE: THE IMPORTANCE OF UNDERSTANDING NEWTON'S THIRD LAW

David E. Brown

Physics Department
University of Massachusetts
Amherst, Massachusetts 01003

January 18, 1988

Abstract

Clinical interview and diagnostic test data are presented that indicate that many students harbor a general naive view of force as an acquired or innate property of single objects rather than that of forces arising from an interaction between objects. Thus some students view objects as inherently more "force-full" by virtue of their mass, speed, activity, etc. This suggests that Newton's Third Law, which makes explicit the relational quality of forces, may play a more important role than is ordinarily granted in teaching. If students acquire a deep understanding of the Third Law, they might be much less apt to have difficulty with both quantitative problems requiring the identification of forces and qualitative problems such as those drawing out the "impetus" misconception, in which many students view force as a property of a moving object causing it to move with constant velocity.

Paper presented at AAPT, Crystal City VA, January 1988

Research supported by NSF grant #MDR 8470579

school textbook (Haber-Schaim, Dodge, & Walter, 1986) speaks of "Newton's Law" (meaning the quantitative statement of Newton's second law) rather than speaking in plural of Newton's laws.

By contrast, many textbooks treat the Third Law in passing, either simply mentioning it briefly as an unsupported statement of fact or as an addendum to the section covering conservation of momentum. The results of this study indicate that this type of treatment is insufficient to counter the misconceptions students hold about the Third Law. This might be a small concern if the Third law is in fact only an insignificant piece of the Newtonian picture, but in this paper it is argued that the Third Law should be treated as a much more significant part of an introductory physics course since it is important for developing the students' qualitative concept of force.

Method

The data in this paper come from three sources: 1) an interviewing study involving oral tutoring, 2) an interviewing study involving tutoring with written materials, and 3) a multiple choice diagnostic test. The oral tutoring study involved a small sample of five students. One of the questions in this tutoring study concerned comparing the force a moving cue ball exerts on a stationary eight ball with the force the eight ball exerts on the cue ball when they collide.

The tutoring study involving written materials is described in more detail in Brown and Clement (1987b) and Brown (1987). In this study, 21 pre-physics high school students were given written explanations of why

a table exerts a force upward on a book resting on the table, with pre and post questions to assess the effect of the explanations. One of th post questions was the steel blocks problem asking about the relative magnitudes of the forces a 200 pound steel block and a 40 pound steel block exert on each other when the 200 pound block is resting on top of the 40 pound block.

The multiple choice diagnostic test was administered to seven physics classes in two high schools (see Brown and Clement, 1987a, for the complete test). The science curriculum in the schools was typical with students taking physics generally in their senior year following chemistry. All of the questions concerned the concept of force in various contexts, and the majority could be answered using a basic knowledge of Newton's Third Law. The test was administered at the beginning of the year and again after all instruction in mechanics had been completed in order to assess gains from instruction (teachers were not aware of the contents of the test). In addition to answering the questions, students were asked to rate how confident they were in their answers. Scores are reported only for students who took both the pre-course and post-course tests (a total of 78 students).

Results

This section will review the relevant results from each of the three studies, examining the data from the studies which converge on a general naive view of force as a property of single objects (objects "having" more or less force and thus being more or less "force-full").

This is opposed tc the Newtonian view of forces arising from interactions between objects.

Interviewing Study Involving Oral Tutoring

In the oral tutoring study, every one of the five students answered with high confidence that the moving cue ball exerts a greater force than the stationary eight ball when they collide. In every case, the justification given for this conclusion was that the moving ball "had" more force, and thus exerted a greater force in the collision. Two examples are given below:

S1: I think that the moving object has more force...I think the cue ball has greater force when they collide because the eight ball is then moved.

S2: I think because the cue ball is moving and the eight ball is stationary, that it's going at a faster rate, and when it strikes it has more force.

Three of the five students discussed the moving ball not only as "having" force, but also as able to transfer that force during the collision.

S1: If the eight ball were moving back against the [stationary] cue ball, the eight ball would have more force, but the only force that would be transferred would be that which the stationary one could absorb before it moves in the same direction as the eight ball.

S3: The force from the moving ball would be transferred to the stationary ball, so the force would move from the moving ball to the ball that wasn't moving.

Interviewing Study Involving Tutoring with Written Materials

Such a conception of force, as a property of single objects rather than as arising from an interaction, can be observed in problems involving static situations as well, as illustrated by the following transcript segments from the tutoring study using written materials. In the steel blocks problem, a 200 pound steel block (block A) rests on top of a 40 pound steel block (block B), and the student is asked to compare the force A exerts on B with the force B exerts on A (see figure 1d). The following student expressed a belief that since the heavier block "had" more force, not only would it exert a greater force, it would push the lighter block into the ground.

S4: I think it [the 40 pound block B] exerts a force up, but I don't think it exerts enough to stop A [the 200 pound upper block] 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.

This next student also felt the weight of each block determined the force it could exert.

S5: Using weights makes me feel more sure about myself, ah, for some unknown reason. Maybe it's, maybe it's just because they're strewn out in front of me. But, um, so I'm more, I'm fairly confident that this box [the 40 pound block on the bottom] is putting up a resisting force to A which is more on top. I would say that A and B exert a force on each other, but A exerts a larger force, more weight, and covers the entire face of this box, with 200 lbs. of pressure which is 160 more lbs. pushing down on the box.

These answers were given after a full page explanation of Newton's Third Law which gave numerous examples from everyday experience, yet

none of the students made even the slightest reference to the Third Law in their explanations.

Multiple Choice Diagnostic Test

That problems involving the Third Law are difficult for students even after instruction was certainly born out by the results of the diagnostic test. For the 78 students tested, the thirteen Third Law questions were answered correctly only 44% of the time on the post-test, a 21% gain from the average pre-test score of 23%. The data in the multiple choice diagnostic study also support the view that many students adopt a concept of force as an innate or acquired property of objects rather than as arising from an interaction between objects. Six problems in particular on the diagnostic would tend to draw out this conception of force (see figure 1). In each of these problems, there is an object which is more or less unambiguously stronger, faster, heavier, more acting as an agent of causation than the other object, or some combination of the above.[1] Students with a concept of force as an innate or acquired property of objects would be expected to answer that the heavier, faster, etc., object (the object which "has" more force) would exert the greater force, while the other object would exert either a lesser force or no force at all. Each of these problems had six answer choices (see figure 2) which were slight variations on the following: 1) A exerts a greater force, 2) B exerts a greater force, 3) the forces are equal, 4) only A exerts a force, 5) only B exerts a force, and 6) neither exerts a force. The one exception is Pulling Blocks A, which had only choices 1-3.

As an example consider the bowler problem (figure 1e) in which the student is asked to compare the force a 16 pound bowling ball exerts on a 4 pound pin when the ball strikes the pin. In this case the student might consider the bowling ball to be clearly more "force-full" because it is moving, it is heavier, and it is more able to cause damage than the pin. The two answers (of the five possible incorrect answers) consistent with this view of force are that the bowling ball exerts a greater force than the pin or that the ball exerts a force while the pin exerts no force at all.

Table 1 shows the percentage of students answering correctly for each of these six problems. Table 2 shows the overall percentage of students giving answers consistent with a "force-fullness" view of force for these six problems. Table 3 shows what percentage of incorrect answers the "force-fullness" answers represent. Thus, for example, table 2 shows that on the pre-test, 46% of the students gave answers for the stock cars problem which were consistent with the view of force as an innate or acquired property. Table 3 shows that these particular incorrect answers represent 56% of all incorrect answers for this problem. On both the pre-test and the post-test, of the students answering incorrectly, in all cases the answers consistent with a "force-fullness" conception of force represented over 50% of the incorrect answers and for most problems was a much higher percentage. If students were drawn equally to each of the distractors, one would expect that the two answers consistent with the view of force as

property would claim only about 40% of the incorrect answers. As can be seen from the totals in table 3, 79% of the incorrect answers on the pre-test and 85% of the incorrect answers on the post-test were of this form. This provides strong evidence that the answers consistent with a "force-fullness" view of force were quite compelling for students.

Particularly striking are the results of the bowler problem. In this problem, students might tend to think the bowling ball "has" more force than the pin since it is both heavier and it is moving. This would translate into answering that the bowling ball exerts a greater force than the pin, which exerts a lesser force or no force at all. All incorrect answers (except for a single response on the post-test) were of this type for this problem on both the pre-test and the post-test. That a "force-fullness" conception is so compelling to students on this problem may explain its exceptional difficulty, as only 5% answered the question correctly after a full year of traditional high school physics instruction. Thus the diagnostic test data support the hypothesis that the great majority of students have a conception of force as a property of objects, as the great majority gave answers consistent with this conception. Further, traditional instruction seems to have had a disappointingly low impact on this conception for these students.

Students' Concept of Force: The Importance of the Third Law

The above results indicate that the low scores on the post-test of the multiple choice diagnostic may not imply simply a failure to remember a verbal statement of the Third Law but rather may indicate a

failure at a deeper conceptual level. This section will further explore the non-Newtonian "force-fullness" view of force and examine the consequences of such a view. It is argued that if students can gain a deep conceptual grasp of Newton's Third Law, they are in a much better position to answer both qualitative and quantitative questions involving forces.

The Newtonian View: Forces Arise from Interactions

Before proceeding to a further discussion of students' conceptions of force, it is helpful to consider the Newtonian view. There are at least five ideas important in a careful consideration of the Third Law in classical mechanics which are elaborated below:

1) A body cannot experience a force in isolation. There cannot be a force on a body A without a second body B to exert the force.

2) Closely related to the above point is the fact that A cannot exert a force in isolation. A cannot exert a force unless there is another body B to exert a force on A. We then say that A and B are interacting. (Thus, for example, it is incorrect to say that an astronaut punching empty space with his fist is exerting a force since there is nothing exerting a force back against his fist.) The attractive or repulsive force between two bodies arises as a result of the action of the two bodies on each other because they are either in contact or experience between them a force acting at a distance.[2]

3) At all moments of time the force A exerts on B is of exactly the same magnitude as the force B exerts on A.

4) An important implication of the above point is that neither force precedes the other force. Even though one body might be more "active" than the other body and thus might seem to initiate the interaction (e.g. a bowling ball striking a pin), the force body A exerts on body B is always simultaneous with the force B exerts on A.

5) In the interaction of A with B, the force A exerts on B is in a direction exactly opposite to the direction of the force which B exerts on A.

Thus, the Third Law can be seen to be much more involved than i implied by the simple epigrammatic version "for every action there is an equal and opposite reaction."

Students' View: Force as an Innate or Acquired Property

The concept of force as embodied in the Third Law and developed above does not seem to be the naive conception of force which most high school students hold. Minstrell and Stimpson (1986) have proposed that in addition to viewing forces as pushes or pulls, students treat force as a property of objects. Such student reasoning has also been observed in studies at the University of Surrey (Watts, 1983) and at the

University of Massachusetts (Brown and Clement, 1987b, Brown, 1987). In this view single objects "have" force as a result of qualities of the object which would make it seem "force-full."

Minstrell and Stimpson list such factors as an object's weight, motion, activity, or strength as important to students in determining an object's force. These factors fit well with Maloney's (1984) data. A student holding this view would consider a heavy, fast-moving, strong football player to have a great deal of "force-fulness." This football player would be able to exert more force on other people or objects "having" less force than they would be able to exert back. This is in direct contrast to the Newtonian concept in which a force does not exist except as arising from the interaction of two objects, the forces on each object being equivalent in magnitude.

Consequences of the View of Force as a Property

There is some reason to believe that a naive view of force as a property sabotages both conceptual understanding and quantitative problem solving ability. In the area of qualitative conceptual questions, a well known failure of students to consider forces as arising from interactions comes from their attempts to answer questions which draw out the "impetus" misconception. Students who give impetus explanations of motion (objects "having" force which keeps them in motion) are not thinking of forces as arising from interactions since they describe the force as a property of the moving object (cf. Fischbein, Stavy, and Ma-Naim, 1987). Also, in many of these problems,

there is only a single object involved (e.g. a rocket floating in space, Clement, 1982).

In the area of quantitative problem solving, Heller and Reif (1984) present a study indicating what student performance could be solving quantitative problems if, among other things, they had a concept of forces arising from interactions between objects. In this study, Heller and Reif compared problem solving performance under two different conditions. In one of these (the model condition) students were given a number of instructions in real time while solving the problems. It is important to indicate here that this was not a teaching study. Students were not given instructions and left alone. Rather, the experimenter stayed with the student and gave explicit guidance, while the student was solving the problem, about constructing an accurate motion description and an accurate force description. The purpose of the experiment was to see what abilities the student would need to internalize in order to be an effective problem solver.

The guidance given for constructing the force description was explicit instructions to consider all the interactions (objects in contact and forces acting at a distance) in the system and indicate equal and opposite forces for those interactions, thus helping the students to view forces as arising from interactions. Subjects guided by the model constructed accurate force descriptions 100% of the time, compared to 46% of the time in the unguided control group. The group guided by the model arrived at the correct final answer to the quantitative problems 92% of the time versus only 21% of the time for the control group. This indicates that a conception of forces arising

only from interactions would aid problem solving if internalized by students.

The Importance of the Third Law

Since the concept of forces arising from interactions between objects is at the heart of the Third Law, it seems from these considerations that a careful and extended treatment of Newton's Third Law may be quite important in an introductory physics course. In teaching Newton's Laws, nowhere else does such a conception of force play an integral role. The first law is concerned with the motion of single objects in the absence of net forces. The second law is concerned with the motion of single objects under the influence of forces of often unknown origin (e.g. find the acceleration of an object of 2kg which has a net force of 3N acting on it in a westward direction. The student may well conceive of this force as something like an "impetus" force).

It is in studying the Third Law that students must come to grips with the conception of forces arising solely from interactions. If students acquire a deep understanding of the Third Law, they might be much less apt to have difficulty with both quantitative problems (as demonstrated by the Heller and Reif study) and qualitative problems such as those drawing out the "impetus" misconception in which force is viewed as a property of a moving object causing it to keep moving.

A Simple Solution?

A possible solution to students' difficulties with the concept of force as an innate or acquired property of objects is to simply re-label their naive concept of force by calling it, for example, "momentum" or "kinetic energy." Both of these can be considered properties of an object, both do depend on the object's mass and speed, and both can be transferred, in whole or in part, in a collision. But this is not a satisfactory solution for at least three reasons: 1) Momentum or kinetic energy do not cause motion (as students view force causing motion), they are simply properties of a moving object arising as a result of the motion of that object. 2) Momentum and kinetic energy vary with the frame of reference. If a student were to simply re-label his conception of force to be, for example, momentum, she might well ask how an object could have a lot of force (or strength or forcefulness) in one frame of reference and none from another perspective. 3) If a student is encouraged to equate momentum with her naive conception of force, she is likely to add momentum to force in problem solving or be confused about why it is improper to do so.

Conceptual Change Necessary

For the above reasons, re-labeling the student's naive concept of force is not a satisfactory solution to the problem of the naive view of force as a property and may lead to even greater confusion (how many times have students used the words "the force of momentum" in a physics

class?). What is necessary is a modification of the concept itself. This modified conception of force should involve a deep understanding (rather than a mere memorization) of the Third Law, that is, a concept of forces arising only from interactions between two objects rather than force as an innate or acquired property of single objects.

Conclusion

The results of the pre-course diagnostic indicate that high school students enter physics classes with preconceptions in the area of Newton's Third Law. Evidence from the post-course diagnostic indicates that these preconceptions are persistent and difficult to overcome with traditional instructional techniques. The data from all three studies support the hypothesis that the persistence of preconceptions concerning the Third Law may result from students' general naive view of force as a property of single objects rather than as a relation between objects.

It has been argued that the consequences of such a view of force extend beyond problems explicitly treating the Third Law to all problems, both quantitative and qualitative, which deal with forces. This suggests that ideas concerning the Third Law, which makes explicit the relational quality of forces, may play a more important role than is ordinarily granted in teaching. Helping students develop a mature conception of force will undoubtedly involve an extended and multi-pronged approach, but innovative strategies for teaching the Third Law should comprise a significant part of the unit on forces and

Newton's Laws rather than receiving the cursory treatment which the Third Law has usually been afforded.

Notes

1) Maloney (1984) describes a study designed to explore which of several of these factors are most important in determining students' answers to problems such as the pulling blocks problems. In particular he examines whether students view the mass of an object or whether the object acts as an agent of causation as more important in determining their answer to the question of which object exerts the greater force. In PULLING BLOCKS A presented here, block A is both heavier as well as being the agent of causation in the interaction, pulling block B to the left, whereas in PULLING BLOCKS B, A is heavier but it is not the agent of causation. Because of this conflict of influences in PULLING BLOCKS B, data is presented here only for PULLING BLOCKS A.

2) Of course even "contact" forces are considered electromagnetic forces acting at a distance on the atomic or molecular level. However, on the macroscopic level, the distinction between "contact forces" and "forces at a distance" provides a helpful dichotomy.

3) Problem taken from Maloney (1984).

References

Boyle, R. K., & Maloney, D. P. (1986). Effect of written text on Newton's Third Law rule usage. Unpublished manuscript, Physics Department, Creighton University, Omaha, Nebraska.

Brown, D. (1987). Using analogies and examples to help students overcome misconceptions in physics: a comparison of two teaching strategies. Unpublished doctoral thesis, University of Massachusetts.

Brown, D., & Clement, J. (1987a). Misconceptions concerning Newton's law of action and reaction: the underestimated importance of the third law. In J. D. Novak (Ed.) Proceedings of the Second International Seminar, Misconceptions and Educational Strategies in Science and Mathematics, vol. III (pp. 39-53). Cornell University, July 26-29, 1987.

Brown, D., & Clement, J. (1987b). Overcoming misconceptions in mechanics: a comparison of two example-based teaching strategies. Paper presented at the conference of the American Educational Research Association, Washington, DC.

Clement, J. (1982). Students' preconceptions in introductory mechanics. American Journal of Physics, 50, 66-71.

Driver, R., & Erickson, G. (1983). Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. Studies in Science Education, 10, 37-60.

Fischbein, E., Stavy, R., & Ma-Naim, H. (1987). The psychological structure of naive impetus conceptions. In J. D. Novak (Ed.) Proceedings of the Second International Seminar, Misconceptions and Educational Strategies in Science and Mathematics, vol. III (pp. 143-151). Cornell University, July 26-29, 1987.

Haber-Schaim, U., Dodge, J. H., & Walter, J. A. (1986). PSSC Physics: sixth edition. Lexington, Massachusetts: D.C. Heath and Company.

Heller, J. I., and Reif, F. (1984). Prescribing effective human problem-solving processes: problem description in physics. Cognition and Instruction, 1, 177-216.

Maloney, D. P. (1984). Rule-governed approaches to physics - Newton's Third Law. Physics Education, 19, 37-42.

McCloskey, M. (1983). Intuitive physics. Scientific American, 248, 122-130.

McDermott, L. (1983). Critical review of research in the domain of mechanics. Paper presented at the International Summer Workshop: Research in Physics Education, La Londe Les Maures - France, June 26 - July 13, 1983.

McDermott, L. (1984). Research on conceptual understanding in mechanics. Physics Today, 37, 24-32.

Minstrell, J., & Stimpson, G. (1986). Students' beliefs in mechanics: cognitive process frameworks. Proceedings of the Fifth Conference on Reasoning and Higher Education, Boise, Idaho.

Sjoberg, S., & Lie, S. (1981). Ideas about force and movement among Norwegian pupils and students. Technical Report 81-11, University of Oslo.

Terry, C., & Jones, G. (1986). Alternative frameworks: Newton's Third Law and conceptual change. European Journal of Science Education, 8, 291-298.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1, 205-221.

Warren, J. W. (1979). Understanding force. London: John Murray.

Watts, D. M. (1983). A study of schoolchildren's alternative frameworks of the concept of force. European Journal of Science Education, 5, 217-230.

Table 1

PERCENT CORRECT FOR THE SIX "FORCE-FULLNESS" PROBLEMS
(n = 78)

	Pretest	Posttest
Stock Cars	18%	27%
Stationary Boxes	10	32
Office Chairs	17	44
Steel Blocks	12	51
Bowler	1	5
Pulling Block A	29	47
Total	14%	33%

Table 2

PERCENTAGE OF ALL ANSWERS (CORRECT AND INCORRECT)
CONSISTENT WITH A CONCEPT OF FORCE AS A PROPERTY OF OBJECTS
(n = 78)

	Pretest	Posttest
Stock Cars	46%	58%
Stationary Boxes	54	46
Office Chairs	77	53
Steel Blocks	78	40
Bowler	99	94
Pulling Block A	51	46
Total	67%	56%

Table 3

PERCENTAGE OF INCORRECT ANSWERS CONSISTENT WITH
A CONCEPT OF FORCE AS A PROPERTY OF OBJECTS
(n = 78)

	Pretest	Posttest
Stock Cars	56%	79%
Stationary Boxes	60	68
Office Chairs	92	93
Steel Blocks	88	82
Bowler	100	99
Pulling Block A	71	85
Total	79%	85%

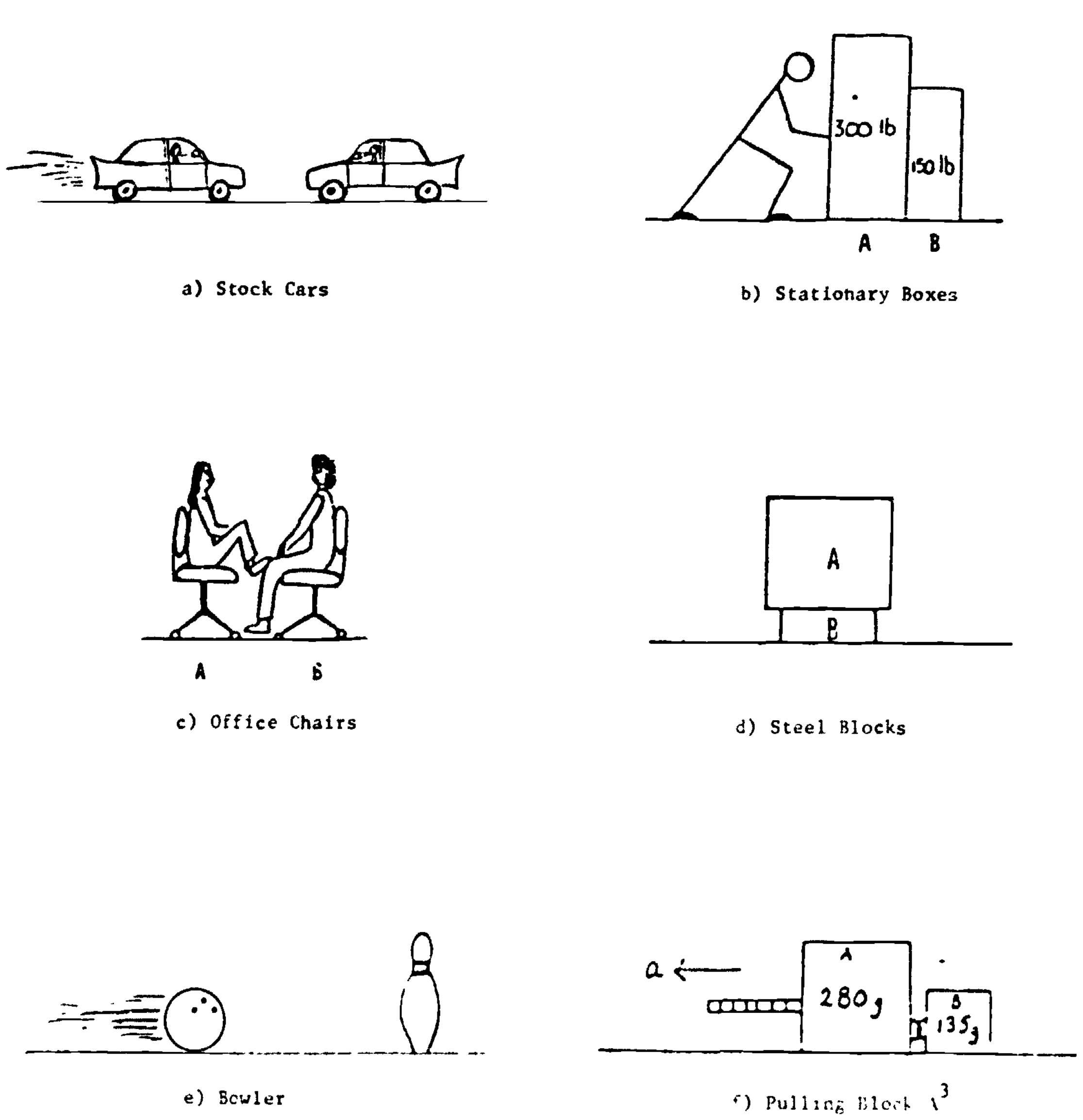

Figure 1

Problems Drawing out "Force-of-[illegible]" Conception

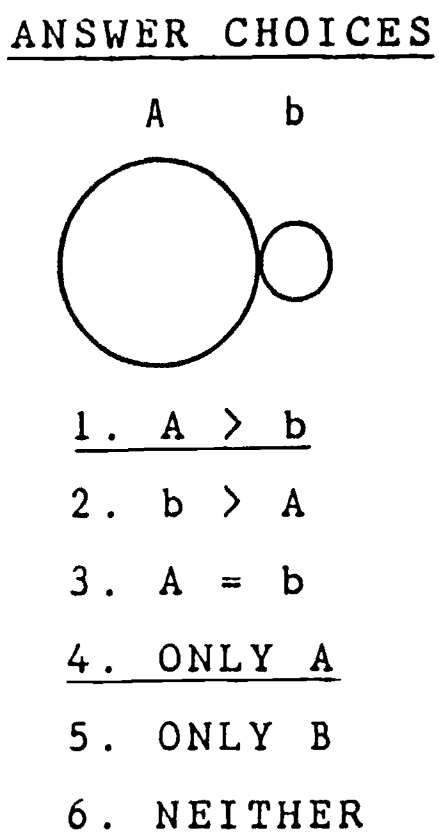

Figure 2

Underlined answer choices consistent

with "force-of-[illegible]" conception