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Curvilinear Motion in the Absence of External Forces: Naïve Beliefs About the Motion of Objects

Abstract. *University students were asked to draw the path a moving object would follow in several different situations. Over half of the students, including many who had taken physics courses, evidenced striking misconceptions about the motion of objects. In particular, many students believed that even in the absence of external forces, objects would move in curved paths.*

In everyday life people constantly observe and interact with objects in motion. We might expect that, as a result of this extensive experience, people would develop a basic understanding of some of the fundamental principles of physics governing the behavior of moving objects. For example, we might expect them to know that objects move in straight lines in the absence of external forces and that falling objects accelerate.

Instruction is probably necessary to achieve an understanding of complex principles or to appreciate the details of fundamental laws (such as the fact that bodies in free fall on the earth undergo a constant acceleration of 9.8 m/sec^2). Furthermore, in some respects perceptual experience can be misleading. For instance, everyday experience suggests that objects set into motion eventually come to a stop when no obvious external force acts on them. Thus, it is not surprising that many people who lack formal instruction in physics do not grasp the principle of inertia (*1*).

Nevertheless, it seems that normal experience should be sufficient for a basic understanding of many simple mechanical principles. However, several experiments that we recently conducted with university students suggest that this is not the case. The experiments are part of a larger project that seeks to characterize internal representations of the physical world in people with various degrees of expertise in physics. The results clearly indicate that many students who have completed one or more physics courses, as well as many of those without formal instruction, fail to understand the most fundamental principles of mechanics. Furthermore, the data suggest that the students do not merely lack such knowledge; they espouse "laws of motion" that are at variance with formal physical laws.

In this report we describe the results of an experiment designed to assess understanding of the principle that objects move in straight lines in the absence of external forces. The subjects were 50 students enrolled in undergraduate courses at Johns Hopkins University. Three subjects failed to follow instructions. Of the remaining 47 subjects, 15 had taken no high school or college physics courses, 22 had completed one high school course, and 10 had completed at least one college physics course. Each subject was presented with 13 simple problems. Each problem consisted of a line drawing and instructions that explained the drawing and specified the subject's task. The drawings for the four problems discussed in this report are shown in Fig. 1.

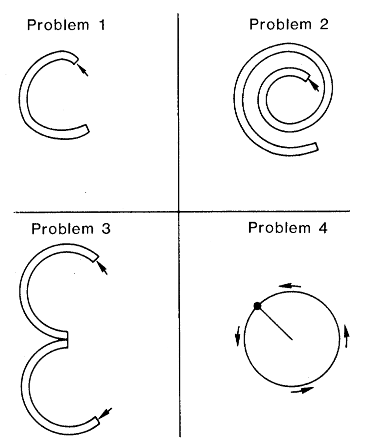

Fig. 1. Drawings for the four problems.

In problems 1 to 3, the subjects were instructed as follows:

> Each of the first several pages shows a thin curved metal tube. In the diagrams you are looking down on the tube. A metal ball is put into the end of the tube indicated by the arrow. The ball is then shot out of the other end of the tube at high speed. Your task is to draw the path the ball will follow after it comes out of the tube. . . . In drawing the path of the ball ignore air resistance. Assume that the ball will come out of the tube at the same speed for all of the tubes.

In problem 3, the subjects were also told that a ball is shot out of each of two tubes and that they should draw the paths of both balls.

In problem 4, the subjects were told:

> Imagine that someone has a metal ball attached to a string and is twirling it at high speed in a circle above his head. In this diagram you are looking down on the ball. The circle shows the path followed by the ball and the arrows show the direction in which it is moving. The line from the center of the circle to the ball is the string. Assume that when the ball is at the point shown in the diagram, the string breaks where it is attached to the ball. Draw the path the ball will follow after the string breaks. Ignore air resistance.

Many of the students clearly did not know that objects move in straight lines when no external force acts on them. Fully 36 percent of the pathways drawn were curved lines. More specifically, the paths were curved in 49 percent of the drawings by students with no formal physics instruction, 34 percent of the drawings by students who had taken one high school physics course, and 14 percent of the drawings by students who had completed one or more college courses.

Figure 2 presents the correct response and the most common erroneous responses to each of the four problems. Consider first the problems involving tubes (problems 1 to 3). For the simple C-shaped tube, one-third of the subjects drew a curved pathway for the ball (Fig. 2B). The results were even more striking for the spiral tube: half of the subjects drew curved lines. Of particular interest is the fact that for 19 of the 25 subjects who drew curved paths for at least one of the first two problems, the path drawn for the spiral tube (Fig. 2D) had a greater curvature than the path drawn for the C-shaped tube (Fig. 2B).

These results suggest that many people believe that when an object is passed through a curved tube, it will continue in curved motion even when no external forces act on it. Furthermore, some people believe that the more dra-

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matic the curvature of the tube (or perhaps the longer the object is in the curved tube), the more curved its motion will be after it emerges.

The data for the problem involving two tubes (problem 3) show that the results for the first two problems do not represent some misunderstanding of the problems by the subjects (for example, a belief that the tubes were oriented vertically, so that the diagram presented a side view). For this problem approximately one-third of the students drew clearly diverging pathways for the two balls (Fig. 2F).

Finally, consider problem 4, in which a ball spinning around at the end of a string flies off when the string breaks. In terms of physical principles, this problem is similar to the tube problems. In both types of problems, a force exerted on an object causes it to move in a curved path and the force is then removed. Not surprisingly, the results for problem 4 were similar to those for problems 1 to 3: 30 percent of the subjects believed that the ball would follow a curved path after the string broke. A typical response of this type is shown in Fig. 2H (*2*).

Two additional types of incorrect responses, which may be termed sophisticated errors, were also observed for problem 4. Three subjects believed that the ball would follow a straight path that continued the line formed by the string at the point at which it broke (Fig. 2I). Interviews revealed that this response represents an attempt to analyze the situation in terms of the forces acting on the ball. Specifically, these subjects believed that a centrifugal force was pulling the ball outward, but that the string was holding the ball in. Thus, when the string broke, the centrifugal force yanked the ball outward, causing it to follow a path that continued the line of the string (*3*).

In the second type of sophisticated error (also made by three subjects), it was thought that the ball would travel in a straight line oriented approximately midway between the path the ball would actually follow and the path leading along the line of the string (Fig. 2J). Interviews revealed that this response was made when subjects considered both centrifugal force and instantaneous velocity of the ball at the point where the string breaks, so that motion of the ball was seen as a compromise between motion in the direction of the velocity vector and motion produced by supposed centrifugal force.

The fact that most subjects who made errors gave the same erroneous response (a curved path for the ball) in all four problems suggests that these subjects were not simply responding randomly, but rather were basing their responses on a system of naïve laws of motion (*4*). Also, given that the errors were consistent across subjects, it does not appear that each individual had a unique set of misconceptions.

An important question concerns the nature of the naïve beliefs about motion that led many of our subjects to draw curved trajectories. The interviews conducted after the experiment provide some answers to this question. Most of the subjects who drew curved pathways believed that an object moving through a curved tube (or otherwise forced to travel in a curved path) acquires a "force" or "momentum" that causes it to continue in curvilinear motion for some time after it emerges from the tube. However, the force or momentum eventually dissipates, and the object's trajectory gradually becomes straight. (The eventual straightening of the trajectory is evident in the drawings of many of the subjects.) One subject explained the curved path she had drawn by stating that "the momentum from the curve [of the tube] gives it [the ball] the arc . . . the force from the curve eventually dissipates and it will follow a normal straight line." Another subject, who had completed 1 year of high school physics and 1 year of college physics, expressed essentially the same belief in somewhat different terms: "The momentum that is acquired as it went around here [through the tube]—well, the force holding it in has given it angular momentum, so as it comes around here [out of the tube] it still has some of that momentum left, but it loses the momentum as the force disappears."

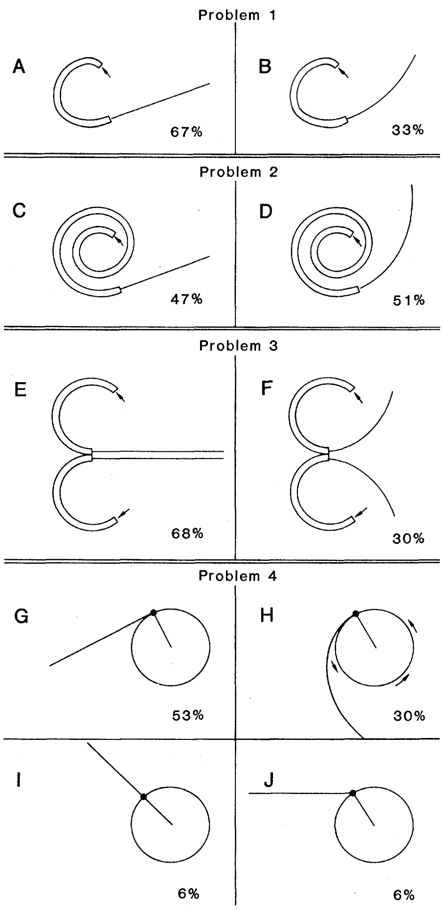

Fig. 2. Correct and most common incorrect responses to the problems. The correct responses appear in (A), (C), (E), and (G). The percentage shown for each drawing gives the percentage of subjects who made that response.

These beliefs are strikingly reminiscent of the medieval theory of impetus, which claimed that an object set in motion acquires an impetus that serves to maintain the motion. According to some versions of the theory, the impetus gradually dissipates, causing the object to decelerate and eventually stop (*5, 6*). Some impetus theorists postulated a circular impetus that served such purposes as sustaining the rotation of a wheel and maintaining the motion of the celestial spheres around the earth. Buridan (*7*), writing in the 14th century, stated the impetus theory as follows: "The motor [i.e., the agent that sets an object in motion] in moving a moving body impresses in it a certain impetus or a certain motive force of the moving body, [which impetus acts] in the direction toward which the mover was moving the moving body, either up or down, or laterally, or circularly."

Clement (*8*) noted misconceptions involving impetus in students solving problems somewhat more complex than those in our experiment. Furthermore, we have found evidence of naïve beliefs resembling the impetus theory in a wide variety of simple situations (an object falling off a cliff, a ball rolling along a flat surface). Thus it appears that belief in a force that maintains motion may color the understanding of motion in people who lack expertise in physics.

Psychologists have devoted a great deal of attention to nonveridical perceptions and invalid reasoning processes (*9*). However, in the development of models of knowledge it has usually been assumed that the information represented is correct. At least in the study of adult cognition, little consideration has been given to the possibility that knowledge representations may frequently be at variance with physical reality (*10*). Cognitive scientists should seek to characterize the "knowledge" that people acquire from their experience with the physical world (*11*) and should try to discover how this knowledge is obtained.

Our results and those of other investigators (8, 12) suggest that educators in the sciences should not treat students as merely lacking the correct information. Instead, educators should take into account the fact that many students have strong preconceptions and misconceptions (8) and problem-solving strategies that are different from those used by experts (12). When a student's naïve beliefs are not addressed, instruction may only serve to provide the student (as, for example, our subject who spoke of angular momentum) with new terminology for expressing his erroneous beliefs.

The Aristotelian view of motion, that an object remains in motion only so long as it is in contact with a mover, historically preceded the impetus theory. It has been described as the most natural way to conceptualize motion (5). Why, then, did our subjects evidence beliefs that echo medieval thinking rather than Aristotelian concepts?

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References and Notes

1. Indeed, the history of science suggests that the principle of inertia is not easily developed on the basis of experience with the world. A coherent statement of this principle was not made until the 17th century.
2. J. Piaget [*The Grasp of Consciousness* (Harvard Univ. Press, Cambridge, 1976)] presented children with a situation similar to that described in our problem 4. The children were given a ball attached to a string and were asked to swing the ball in a circle with the string. They were then to release the string so that the ball would hit a target. Piaget was concerned with the relation between what the children did in attempting to hit the target and what they said they did. However, he mentioned that in describing the behavior of the ball even the youngest child said that it followed a straight line when the string was released. Of course, unlike the subjects' reports in our experiment, the children's descriptions of the ball's behavior were based on observation of the ball. Thus, Piaget's result illustrates the point that it is unlikely that nonveridical perception of situations like those depicted in our problems is the source of our subjects' belief that the balls would follow curved trajectories.
3. J. Larkin, J. McDermott, D. Simon, and H. Simon [C.I.P. No. 408, Carnegie-Mellon University (1979)] suggested that, at least for physics experts, knowledge used in solving textbook physics problems is organized into several different approaches or methods. A person working on a problem adopts a particular approach and attempts to solve the problem by applying the principles appropriate to that approach. According to this view, our subjects who made sophisticated errors adopted an inappropriate approach (a "forces" approach). Also the knowledge about forces that these subjects applied included misconceptions about centrifugal force. As a result, the subjects arrived at incorrect answers to the problem.
4. We are suggesting that people, through their experience with the physical world, develop naïve theories of motion which they use to predict and explain the motion of objects. Analogous suggestions have been made in other contexts. A number of social psychologists—for example, F. Heider [*The Psychology of Interpersonal Relations* (Wiley, New York, 1958)]—have argued that, on the basis of social experiences, people develop implicit theories of behavior which they use to predict and explain the actions of others.
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10. J. Piaget [*The Child's Conception of Movement and Speed* (Routledge & Kegan Paul, London, 1970); *The Child's Conception of Physical Causality* (Kegan Paul, Trench, Trubner, London, 1930)] explored children's immature conceptions of various aspects of physical reality. Further, in several studies to which our research appears similar, Piaget and his colleagues [B. Inhelder and J. Piaget, *The Growth of Logical Thinking* (Basic Books, New York, 1958)] examined children's approaches to some simple mechanics problems (for example, what determines the period of a pendulum's oscillation?). However, in these studies Piaget was primarily concerned with characterizing the reasoning processes children use in attempting to solve problems. Physics problems were chosen merely as a convenient vehicle for studying these problem-solving processes. Consequently, little attention was paid to the content of the children's preconceptions.
11. D. Norman [*Cognit. Sci.* **4**, 1 (1980)] expresses a similar view in stating that characterizing the nature and content of belief systems should be a major current goal of cognitive science.
12. J. Larkin, J. McDermott, D. Simon, H. Simon, *Science* **208**, 1335 (1980).
13. Supported by NSF grant SED-7912741 and by biomedical research support grant 5 S07 RR07041-13. We thank H. Egeth, D. Jira, R. Kargon, and G. Petrinicola for their helpful suggestions.

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Neurochemical and Behavioral Evidence for a Selective Presynaptic Dopamine Receptor Agonist

Abstract. *A new dopamine analog, 6,7-dihydroxy-2-dimethylaminotetralin (TL-99), was compared to apomorphine in three tests of dopaminergic function in the central nervous system. The tests, performed on rats, included production of changes in locomotor activity (involving both presynaptic and postsynaptic receptors), inhibition of dopa accumulation (quantifying presynaptic receptor activity), and the rotation model (quantifying postsynaptic receptor activation). Apomorphine was efficacious at both presynaptic and postsynaptic receptors, whereas TL-99 was much more efficacious at the presynaptic receptor. This result indicates not only that differences exist between presynaptic and postsynaptic dopamine receptors, but also that these differences may be exploited in the design of selective dopamine agonists.*

Pharmacological research is focused on developing drugs that selectively alter neurotransmission in specific dopamine pathways (mesolimbic, mesocortical, tuberoinfundibular, or nigrostriatal) or that selectively interact with specific types of dopamine receptors (soma-dendritic, presynaptic, or postsynaptic) (1). Each dopamine receptor has a characteristic function in the brain, with soma-dendritic receptors controlling dopaminergic neuronal activity, presynaptic receptors inhibiting the synthesis and release of dopamine, and postsynaptic receptors mediating the normal physiological response to dopamine characteristic of the particular brain region.

Identification of a drug that selectively activates one subpopulation of dopamine

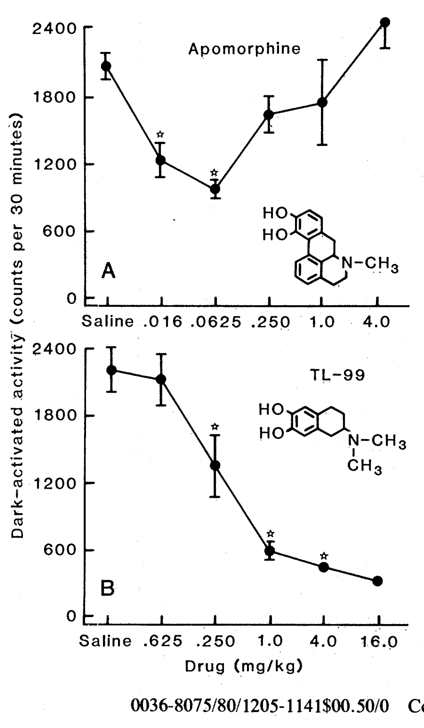

Fig. 1. Comparison of the dose-response curves for apomorphine and TL-99 during dark-activated activity. After 48 hours of exposure to continuous light, two rats were given subcutaneous injections of saline, apomorphine, or TL-99. Five minutes later both rats were placed in a clear Plexiglas cage (14.5 by 50 by 20 cm) on top of an Automex activity meter. The lights were turned off, and activity was determined for 30 minutes by movements of the rats through an electromagnetic field. Two rats were placed in each cage to stimulate each other and therefore raise control activity. Solid circles represent the means, and the vertical lines denote 1 standard error as determined in five groups of two rats. At 16.0 mg/kg, there was only enough TL-99 for one group of two rats. Asterisks indicate a significant decrease ($P < .05$, one-way analysis of variance with least-significant-difference test; two-tailed analysis).

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