Cognition, 9 (1981) 117–123

Naive beliefs in "sophisticated" subjects: misconceptions about trajectories of objects*

ALFONSO CARAMAZZA,
MICHAEL McCLOSKEY
BERT GREEN
The Johns Hopkins University

Abstract

University students were asked to solve simple problems about the trajectories of falling objects. A majority of the students revealed a variety of misconceptions about motion. However, the few basic patterns of responses produced by the subjects suggest considerable commonality in the types of naive physical "laws" people develop on the basis of everyday experience with the world.

The ability to interact successfully with moving objects implies some sort of knowledge about motion. For example, a baseball player who is able to catch a fly ball must have abstracted from his perceptual experience some form of knowledge that enables him to position himself at the location where the ball will land. It is not obvious, however, what *types* of knowledge are acquired through experience. It may be the case that normal experience with moving objects leads to the induction of coherent abstract principles that are in essence consistent with the formal laws of physics: Alternatively, experience may lead only to the acquisition of limited, concrete information about specific situations. The results of several experiments we have recently conducted suggest that people do abstract from their experience with the world general principles concerning the motion of objects. Surprisingly, however, these principles are often strikingly at variance with the most fundamental

*This research was supported by NSF Award No. SED 791241 in the Joint National Institute of Education-National Science Foundation Program of Research on Cognitive Processes and the Structure of Knowledge in Science and Mathematics, and by Biomedical Research Support Grant S507 RR07041-13.

Any opinions, findings, conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation or the National Institute of Education.

Reprint requests should be sent to: Alfonso Caramazza, Department of Psychology, The Johns Hopkins University, Baltimore, Maryland 21218.

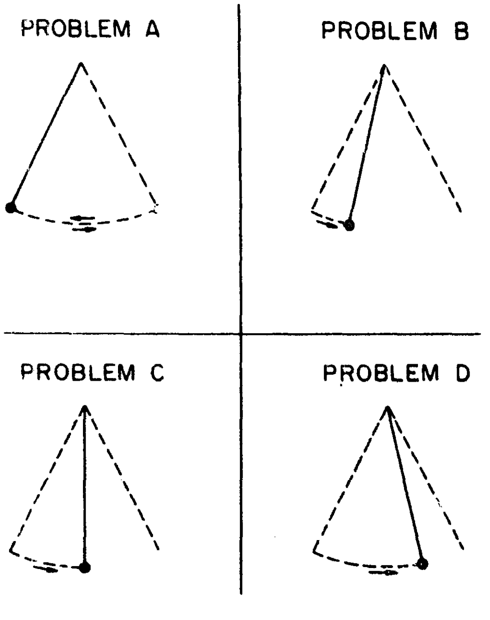
physical laws. Furthermore, the naïve principles are espoused not only by people with no formal instruction in physics, but also by a large proportion of those who have completed high school or college physics courses.

In this report we describe an experiment concerned with people's beliefs about *projectile motion.* Fifty undergraduate students at the Johns Hopkins University served as subjects. Six subjects failed to follow instructions, and their data were not included in our analyses. Of the remaining 44 subjects, 10 had completed at least one college-level course in physics, 20 had taken high school physics, and 14 had received no formal physics instruction at the high school or college level. Each student was asked to solve 13 simple problems, of which 4 will be discussed in this report. These 4 problems, shown as problems A through D in Figure 1, required the students to trace the trajectory of a falling object. The problems were presented separately, one per page, as line drawings of a metal ball suspended by a string.

Subjects were instructed to consider the ball and string depicted in the line drawings as moving in an arc as a pendulum. They were then asked to draw the path the ball would follow if the string were cut when the ball was at the location indicated and moving in the direction indicated in the line drawing.

The results of the experiment are remarkable in what they reveal about subjects' knowledge about motion. Only 25% of the subjects produced responses that demonstrated a basic understanding of projectile motion. The responses of the remaining 75% revealed a variety of gross misconceptions.

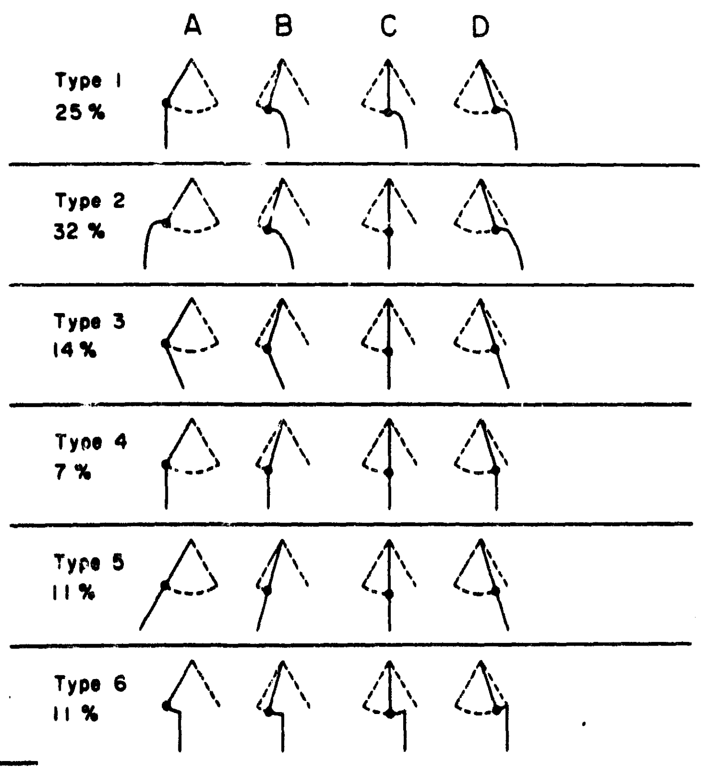
Figure 1. *Line drawings for the four problems.*



We have classified subjects' responses on the four problems into six different types on the basis of criteria described below.[1] An example of each response type is shown in Figure 2, along with the percentage of subjects producing each type of response.

Eleven of the 44 subjects produced the pattern of response referred to as Type 1. As indicated in Figure 2, these 11 subjects drew vertical trajectories for problem A, and parabolic trajectories for problems B, C and D. The Type 1 subjects understand that in Problem A the ball has a velocity of zero when the string is cut, so that the ball's trajectory is determined by the force of gravity alone. Furthermore, the Type 1 subjects are aware that for problems B through D the initial velocity of the ball as well as the action of gravity must be considered in determining the trajectory. Finally, the subjects appear to know that the ball will accelerate as it falls, producing a parabolic trajectory.

Figure 2. *Examples of the six basic response types, with the percentage of subjects who made each type of response.*



[1]To ensure that our classification of subjects' responses was reliable, we gave three undergraduate research assistants the criteria for Types 1 through 6, and asked them to sort the subjects' responses into types. Two of the judges agreed with our classification for all 44 subjects, while the third judge agreed with our classification for 43 of the 44 subjects. (The point of disagreement concerned whether a response was a straight line or a parabolic arc.)

This is not to say, however, that all of the subjects producing Type 1 responses have a full understanding of projectile motion. For example, five of the 11 subjects do not appreciate that the horizontal displacement of the ball will be greater in problem C than in problem B, because of the greater horizontal velocity in problem C. However, this error is a minor one relative to the sorts of misconceptions revealed by subjects producing Type 2–Type 6 responses.

Fourteen subjects (11 of whom had received formal instruction in physics at the high school or college level) produced responses designated as Type 2. These subjects made essentially correct responses to problems B and D, suggesting that they had some understanding of (1) the importance of the initial velocity of the ball, and (2) the fact that the ball accelerates as it falls. However, the Type 2 subjects each made an error on problem A, problem C or both. The eleven subjects who made an error on problem A drew parabolic trajectories to the left (shown in Fig. 2) or to the right of the ball's initial position. This error seems to represent a failure to understand that in problem A the ball has a horizontal velocity of zero, and so will fall straight down. The eight subjects who made an error on problem C (five of whom also erred on problem A) for some reason believed that the ball would fall straight down. Informal questioning of subjects who made this error suggests that it does not represent a failure to realize that the ball is moving horizontally. In fact, most subjects are aware that the velocity of the pendulum is at a maximum at the position shown in problem C. Thus, it appears that the subjects who made straight down responses on problem C believe that when an object is "pointing" straight down, it will fall directly to the ground, regardless of whether or not it is moving.

The responses designated Type 3 were similar to the Type 1 and Type 2 responses, with the exception that all Type 3 trajectories were straight lines. The six subjects who produced Type 3 responses evidence some understanding of the fact that the initial velocity of the ball in problems B and D will result in a horizontal displacement of the ball as it falls. However, the Type 3 subjects fail to understand that the ball will undergo a vertical acceleration as it falls and as a result will describe a parabolic trajectory. In addition, many of the Type 3 subjects made the same sort of errors on problems A and C as did the subjects producing Type 2 responses. Specifically, two of the six subjects believed that the ball would be displaced horizontally in problem A, and four of the six believed that the ball would fall straight down in problem C. Only one of the Type 3 subjects made correct judgements about the horizontal displacement of the ball in all four problems.

The subjects producing Type 4, 5 and 6 responses evidenced misconceptions about motion even more serious than those of the Type 2 and 3 subjects.

Three subjects, whose responses were designated Type 4, believed that the ball would fall straight to the ground in all four problems. These subjects, all of whom had received no formal instruction in physics, fail to understand that the initial velocity of the ball plays a role in determining its trajectory. We have no indication that these subjects have any understanding of projectile motion.

The five subjects who produced Type 5 responses also have gross misconceptions about projectile motion. These subjects drew for all four problems straight-line trajectories that continued the line formed by the string (see Fig. 2). The Type 5 responses may reflect an attempt to analyze the problems in terms of the forces acting on the ball. In other words, the Type 5 subjects may have believed that the string was pulling the ball in one direction while gravity, or perhaps a centrifugal force, was pulling the ball in the opposite direction. Thus, when the string was cut, the ball fell in a direction opposite to that of the force exerted by the string.

Finally, consider the five subjects who produced Type 6 responses. These subjects (all but one without previous instruction in physics) present perhaps the most intriguing conception of projectile motion. The Type 6 subjects believe that when the string is cut, the ball will continue for a short time along its original arc, and then will fall directly to the ground (see Fig. 2). These subjects' ideas about motion seem to be related to the pre-Galilean notion that a moving object is kept in motion by an "impetus" that gradually disspitates[2]. In particular, these subjects apparently believe that the motion of the pendulum imparts to the ball a sort of impetus that causes it to retain the original arc for some time after the string is cut. However, this impetus gradually dies out, at which point gravity takes over and causes the ball to fall directly to the ground.

The results we have reported lead to the conclusion that simple real-world experience with moving objects does not lead naturally to the abstraction of principles that are consistent with the formal laws of motion[3]. It does appear that people develop general beliefs about motion on the basis of their experience—the fact that subjects did not respond randomly to the problems suggests that they were attempting to apply general (but incorrect) beliefs about the behavior of moving objects. In addition, the fact that the subjects' responses fell into a few basic patterns suggests that the naïve beliefs about

[2]For a discussion of the impetus theory and other early conceptualizations of motion, see E. J. Dijksterhuis or M. Clagett.

[3]Indeed, the history of science clearly suggests that experience with moving objects does not readily lead to the construction of the basic laws of motion. The first adequate account of projectile motion was provided by Galileo in the early 17th Century, and not until Newton's *Principia Mathematica* in 1687 was an adequate general description of motion available.

motion are not entirely idiosyncratic. In other words, it appears that experience with the world leads naturally to the development of only a few basic models of motion. Consistent with this view is the fact that the naïve beliefs of many of our subjects were reminiscent of pre-Galilean models of motion. The historical persistence of these beliefs suggests that they are a natural outcome of experience with the world.

In the light of the above comments it is of considerable interest to determine the source of people's beliefs about motion. Although the naïve beliefs would appear to have their origin in experience with moving objects, it is quite unlikely that these beliefs are produced by direct induction from perceptual experience. It is difficult to imagine, for example, how the beliefs reflected in response Type 6 could have developed through induction from real-world experience. It is much more likely that, as Piaget (1971) has argued, deduction plays a crucial role in the development of models of the physical world. On this view, subjective models of laws of motion reflect the conceptual system people use to organize and draw inferences from their experience with moving objects.

Future research needs to address at least three issues. First, there is need to provide a more detailed description of people's beliefs about the behavior of moving objects and, second, an attempt must be made to provide an account of the origin of these beliefs. Finally, it is important to ask what effect formal instruction in physics has on people's conceptions of motion. Our results clearly indicate that formal instruction does not always lead to an understanding of the fundamentals of projectile motion: only 33% of the subjects who had completed a high school and/or a college physics course produced the basically-correct Type 1 responses. Thus, one important topic for future research will be to determine why physics courses do not provide most students with a grasp of even the rather basic principles we have considered here. One possibility is that instruction is frequently ineffective because it fails to take into account students' misconceptions about motion (such as the misconceptions reflected in Type 5 and 6 responses) but instead treats students as if they understand basic principles and only need to learn to formalize and quantify these principles.

Although physics courses clearly did not provide our subjects with a full understanding of the basics of projectile motion, our results suggest that instruction probably has some effect. Specifically, 70% of the subjects with some formal instruction produced Type 1 or Type 2 responses, suggesting that these subjects have at least some understanding of (a) the importance of the ball's horizontal velocity and (b) the fact that the ball will accelerate vertically as it falls. In contrast, 71% of the subjects with no formal instruction produced responses falling into Types 3–6, indicating that these subjects failed to understand the effect of the initial horizontal velocity or the vertical acceleration (Types 3 and 4), or (in the case of Types 5 and 6) had some even more fundamental misconceptions about projectile motion. Although these results suggest an effect of instruction, firm conclusions cannot be made. It is, for example, conceivable that the subjects who have completed physics courses are somehow different from those who lack formal instruction, such that the former would have responded differently from the latter even before taking physics courses. Thus, additional research will be necessary to specify the effects of instruction.

In research currently in progress we are attempting to explore the origins of naïve beliefs about motion, as well as the ways in which these beliefs are altered by instruction in physics. This research should enable us to provide a more detailed characterization of the nature and development of people's conceptions of the physical world.

References

Clagett, M. (1959) *The Science of Mechanics in the Middle Ages.* University of Wisconsin Press, Madison, Wisconsin.

Dijksterhuis, E. J. (1961) *The Mechanization of the World Picture.* C. Dikshoorn, trans., Clarendon Press, Oxford.

Piaget, J. (1971) *Psychology and epistemology: Towards a theory of knowledge.* Viking Press, New York.

Résumé

On a demandé à des étudiants d'Université de résoudre des problèmes simples sur la trajectoire des objets tombants. La majorité de ces étudients s'est révelée avoir des idées fausses sur le mouvement. Les quelques patterns de base qui rendent compte des réponses suggèrent une standardisation considérable des types de "lois" physiques naïves que les gens développent sur la base de leur expérience du monde.