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25. *Note added in proof*: Since this report was submitted, M. Plaut, L. M. Lichtenstein, and C. S. Henney [*J. Immunol.* **110**, 771 (1973)] have also reported that microtubules (and microfilaments) are involved in the cytotoxic process mediated by immune lymphocytes.

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Observation Is Insufficient for Discovering that the Surface of Still Water Is Invariantly Horizontal

Abstract. *Among women college students who did not know that the surface of still water in a bottle is always horizontal, two types of specific task procedures designed to elicit self-discovery of the principle were ineffective. Failure to acquire the concept was reflected in inaccurate responses on the adjustment task and by inability of students to verbalize a correct strategy.*

Years of research involving hundreds of subjects of preschool through college age indicates that by 12 years of age boys understand the principle that the surface of still water remains horizontal (*1*). Girls, however, lag behind boys at all ages in this respect, and about 50 percent of college women still do not know this principle (*1*). We report here two studies which demonstrate that college women who do not know the principle do not readily learn it in tasks designed to optimize self-discovery of the concept.

Figure 1 shows the two parts of the apparatus. On the left is a disk 27.5 cm in diameter on which is mounted a bottle 9.5 cm in diameter and 14 cm tall. This bottle, called the model, is half filled with red water (the bottle is covered in Fig. 1). On the right is half of an identically shaped bottle similarly mounted and called the pretend bottle. It always appears to be half filled with "red water." What is actually visible through the pretend bottle is part of a rotatable disk 24 cm in diameter, half red and half white.

In use, both bottles are positioned to the same clock-numeral orientations (for example, at 1 o'clock the bottles are tilted 30° to the right as in Fig. 1). The subject's task is always to adjust the pretend waterline to the position she believes the real water has taken.

In both studies women were recruited from introductory psychology sections at Pennsylvania State University. Each subject briefly viewed the water in the model as it was rotated. Then a cover (Fig. 1) was placed on the bottle and the subject was asked to adjust the pretend waterline for eight oblique bottle angles, presented in random order: 1, 2, 4, 5, 7, 8, 10, and 11 o'clock. Before each adjustment the pretend waterline was preset to a randomly selected angle that deviated by at least 45° from the horizontal; then the bottles were moved to their appropriate positions. After the subjects' predictive adjustments, which we call the pretest, their responses to the following two interview questions were recorded: (i) "How did you know where to put the pretend water level?" (ii) "What is the principle or the idea which determines where the water goes in the bottle?"

If seven pretest adjustments were within 4° of the horizontal (*2*), the subject was classified "sophisticated" (So) and dismissed. Remaining subjects were classified "naive" (Na) and retained for training. In study 1, 47 subjects were given the pretest to obtain 30 Na subjects. Of 44 subjects recruited in study 2, 33 were defined Na.

Studies 1 and 2 differ in their training conditions. In study 1, one training trial involved these steps. The subject (i) makes a predictive adjustment with the model covered, as in the pretest; (ii) removes the cover from the model revealing the real waterline; (iii) readjusts the pretend waterline to match the real waterline whenever she perceives her adjustment to be in error; and (iv) replaces the cover on the model. Train-

Table 1. Estimated medians (M) and 95 percent confidence intervals (CI) for absolute errors for naive subjects in studies 1 and 2 and for criterion women and unselected men. Results are given in degrees; *N*, number of subjects.

Bottle orientation	Study 1				Study 2				Criterion women ($N = 38$)		Unselected men ($N = 62$)	
	Pretest ($N = 30$)		Block 4*		Pretest ($N = 33$)		Posttest					
	CI	M	CI	M	CI	M	CI	M	CI	M	CI	M
1 o'clock	8.5-23.0	16.0	4.5-11.5	7.0	8.0-14.0	10.5	5.5-11.5	9.0	2.5-4.5	3.5	1.5-3.5	2.5
2 o'clock	9.0-25.0	13.5	3.5- 9.0	6.0	10.0-18.0	14.0	4.0-11.0	6.5	1.5-2.5	2.0	1.5-3.0	2.0
4 o'clock	15.0-29.0	23.0	8.0-21.5	15.0	11.5-21.0	16.0	3.0- 8.0	5.0	1.0-2.0	1.5	1.0-3.0	2.0
5 o'clock	14.0-28.5	19.5	4.0-11.0	7.0	9.5-16.0	13.0	6.0-12.0	9.0	1.0-3.5	2.0	2.0-3.5	2.5
7 o'clock	10.5-20.0	15.0	5.0- 9.0	6.5	8.5-16.5	12.0	7.0-13.0	10.0	1.5-3.5	2.0	1.0-2.5	1.5
8 o'clock	9.0-24.0	17.5	7.0-18.0	11.0	12.0-27.0	20.0	4.0-14.0	8.5	2.0-3.5	2.5	1.5-3.0	2.5
10 o'clock	10.5-24.5	16.5	4.0-10.0	6.5	8.0-16.0	12.0	5.0- 9.5	7.0	1.5-3.5	2.5	1.5-3.5	2.0
11 o'clock	12.5-28.5	20.5	3.0-12.5	6.0	7.5-13.5	10.0	6.5-11.0	9.0	1.0-2.5	2.0	2.0-3.5	2.5

* Predictive settings only, excludes seven who achieved learning criterion.

ing trials were repeated until the subject met the learning criterion of ten successive predictive adjustments within 4° of the horizontal (*2*), or until 48 trials had been completed. Within each block of 12 trials the bottles were positioned to each of the 12 clock-numeral orientations in random order. After training, the subjects were reinterviewed.

In study 2, the model was not covered during training. The subject was told to adjust the pretend waterline to match the visible real waterline. Each subject made 24 adjustments, 2 for each clock-numeral position, randomly ordered within each block of 12 trials. After training, eight posttest predictive adjustments were made exactly as in the pretest, then subjects were reinterviewed.

Our measure of adjustment accuracy is the absolute angular error in degrees, referenced from the horizontal axis which is defined as zero. In Table 1 are reported 95 percent confidence intervals (CI's) and point estimates of the median for symmetric distributions (*3*) for Na subjects. For comparison we provide data for two additional groups of college subjects similarly sampled and tested. The criterion women were those 38 among 72 who were judged only on the basis of their verbal responses to the same interview questions to know that water remains invariantly horizontal. The group of 62 unselected men includes all men similarly tested (*4*). The CI's for these two groups are almost identical for each bottle angle. The predictive adjustments for the So subjects were comparable to the responses for the criterion women. In study 1, initial predictive waterline adjustments (step i) for the bottle angles 12, 3, 6, and 9 o'clock were always accurate (median error 1°), as they are for young children for these bottle angles (*1*). Furthermore, when the real water was visible the pretend waterline adjustments in both studies 1 and 2 were always accurate (median error 0°).

For neither study do the oblique-angle CI's for the Na subjects' pretest performance overlap the CI's for the criterion women group. In study 1, only 7 out of 30 subjects achieved the learning criterion. To indicate the final accuracy of the 23 nonlearning subjects, we report the subjects' predictive adjustments for the oblique angles in the last block of 12 trials, when predictive adjustments were most accurate. For no oblique angle do the CI's overlap the CI's for the criterion women. For three bottle angles, the CI's associated with

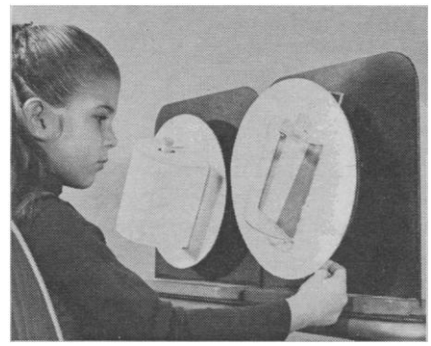

Fig. 1. Child adjusting pretend waterline. The bottle containing water is on the left and is shown covered. Bottles are shown in 1 o'clock position.

the subjects' adjustments in the final block overlap their pretest CI's. In study 2, for no oblique angle on the posttest did the Na subjects' CI's overlap the CI's for the criterion women. Except for one oblique angle, the Na subjects' pretest and posttest CI's overlap. While the predictive adjustments of the Na subjects did improve with training, this improvement does not reflect acquisition of the principle, as demonstrated by responses to interview questions.

The responses of Na and So subjects to these questions were typed on cards. There were two cards for each Na subject, one card for each interview. For each study separately, the cards were scrambled and given to five judges who knew the principle. After a brief introduction to the apparatus task they were instructed to sort the cards into two piles. Cards associated with subjects whose responses indicated that they would make accurate adjustments of the pretend waterline (that is, do well) were to be placed in one pile, and cards associated with subjects that the judges expected to make inaccurate adjustments (that is, do poorly) were placed in the other pile. A single classification was determined for each card, based on a majority decision of the judges.

There was excellent agreement among judges (*5*). All So subjects were classified as being expected to do well. For neither study was there evidence that Na subjects could verbalize an effective strategy before or after training. Of 56 Na subjects from both studies who were expected to do poorly before training, 51 retained this classification after training. Among these 51 were 3 of the 7 subjects who achieved the learning criterion in study 1. The remaining 7 of the 63 Na subjects were expected to do well and may be considered to have been misdiagnosed on the pretest and are probably So (*6*).

We do not maintain that our Na subjects are incapable of learning an "obvious" physical fact about the world, but we do maintain that subjects who perform inaccurately on our task do so because they lack conceptual understanding that still water remains horizontal. The answers provided by our subjects to the interview questions reinforce this belief. In contrast to So subjects who invariably state, for example, that "water is always level," our Na subjects are likely to say, for instance, "water is level when the bottle is upright, but is inclined when the bottle is tilted."

Unfortunately, we do not have a satisfactory explanation for our results, especially when we would expect from theory (*7*) that knowledge of the principle would be acquired years before and probably by self-discovery.

HOBEN THOMAS
WESLEY JAMISON
DONNA D. HUMMEL

Department of Psychology,
Pennsylvania State University,
University Park 16802

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2. The 4° value is an average; the maximum adjustment errors permitted were 3° for bottle angles of 1, 2, 4, 8, and 11 o'clock; 5° for 5 and 10 o'clock; and 8° for 7 o'clock. These values were twice the standard deviation of the prediction responses of the criterion women mentioned later in the report.
3. A review of procedures and theory is given by G. E. Noether [*Amer. Statist.* **26**, 39 (1972)] and originally by J. L. Hodges and E. L. Lehman [*Ann. Math. Statist.* **34**, 598 (1963)] and by E. L. Lehman (*ibid.*, p. 1507). The distribution of errors appears to be double-exponential.
4. It is unusual to find college men who do not know that water remains horizontal. Among the 62 unselected men, only eight were later judged *not* to know the principle by a procedure similar to that described in the report.
5. Of the 28 cards representing all So subjects, five judges agreed on the sorting of 23, and four judges agreed on the sorting of the remaining five. Of the 126 cards representing 63 Na subjects, four or five judges agreed on the sorting of 107 cards; the remaining 19 were decided on the basis of a three to two majority.
6. Of the seven subjects expected to do well before training, six retained this classification after training. Among seven subjects who achieved the learning criterion in study 1, three were judged as expected to do poorly before training and to do well after training; three were judged as expected to do poorly both times; and one was judged as expected to do well both times.
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8. Supported in part by the Central Fund for Research of Pennsylvania State University.

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