Table 1. Isotopic analyses of two vein calcite surfaces from Devils Hole. Dates and 2σ errors were calculated as in (*1*), which corrects for detrital Th and U by assuming a ^{232}Th-bearing component with $^{232}\text{Th}/^{238}\text{U} = 1.21$, $(^{230}\text{Th}/^{234}\text{U}/^{238}\text{U}) = 1$; all ratios are activity ratios. The DH-11 dates in (*1*) are not as sensitive to this assumption (because their $^{230}\text{Th}/^{232}\text{Th}$ ratios are higher), but the surface-sample dates will vary by as much as −5000 to +2000 years for initial ratios that are geochemically reasonable.

Sample	U (ppm)	$^{230}\text{Th}/^{232}\text{Th}$	$^{230}\text{Th}/\text{U}$ date (ka)	Initial $^{234}\text{U}/^{238}\text{U}$
DH-11	0.50	27.3	68 ± 6	3.18 ± 0.20
DH-2	0.48	27.1	64 ± 7	3.08 ± 0.14

of the DH-11 sample core of vein calcite from Devils Hole. However, considerations of the aqueous environment and petrology of the vein calcite argue against the hypothesized mechanism, and a test shows that its effects on the DH-11 dates would be orders of magnitude less than that calculated by Edwards and Gallup.

We have calculated the possible maximum effect on the DH-11 dates assuming that all of the water-generated ^{230}Th was transferred to the wall, using an iterative solution for both ages and growth rates, together with the complete DH-11 data set of U-Th isotopic concentrations (*1*).

Our results show that the potential bias ranges from about 1500 to 3500 years, with the higher figure applying to the samples taken from a depth of 44.5 to 48.5 mm (crucial because of their relatively slow growth rate). Such biases would apply only if all or most of the newly created ^{230}Th atoms in the water came into contact with the walls of the cavern before these atoms were adsorbed onto suspended particulates that then were removed by gravitational settling. Turbulent mixing would be the most efficient mechanism for transferring ^{230}Th atoms from the water to the cavern walls. But, except during earthquakes, turbulence is not observed in Devils Hole. As a result, adsorption of ^{230}Th on the cavern walls would have been governed by diffusion, in competition with gravitational settling.

There is a sensitive and direct test of the hypothesis of Edwards and Gallup. Calcite stopped precipitating onto the walls of the Devils Hole cavern at about 60 ka (*1–3*), so that the proposed mechanism, if significant, should have resulted in a large excess of ^{230}Th built up since then (and only partially diminished by radioactive decay) on the cavern wall surfaces. Even if the proposed process operated at only 5% efficiency, apparent ages of more than 200,000 years would be predicted (if we take into account the competing processes of influx and radioactive decay) for a 50-μm-thick sample of the vein surface, compared with the expected date of approximately 60,000 years (*1, 3*).

We performed this test on two samples (Table 1), one milled from the free surface of the DH-11 core (*1, 2*) (44 μm thick) and another from the free surface of the DH-2 sample (56 μm thick) (*3*).

Taking the surface sample dates at their nominal values of 68 and 64 ka and assuming that the true surface age of the vein should be about 60 ka (*1–3*), we calculated that the transfer efficiency for the water-generated ^{230}Th was 0.6% for sample DH-11 and 0.4% for sample DH-2. Apparently, gravitational settling of adsorbed ^{230}Th is a more efficient mechanism for the removal of water-generated ^{230}Th than is adsorption onto vertical or overhanging walls. Even if the small degree of ^{230}Th excess suggested by the nominal ^{230}Th dates of the surface samples is real (which is not clear, given the uncertainties in the dates), calculations with the complete DH-11 data set show that the resulting effect on the DH-11 dates (*1*) is less than 20 *years* for all samples.

It seems unlikely that the process that resulted in cessation of calcite precipitation in DH-11 and DH-2 about 60 ka coincidentally also inhibited the plating out of ^{230}Th on the walls of Devils Hole only since that time. That a rain of suspended particulates has occurred in Devils Hole for hundreds of thousands of years is indicated by a comparison of vein calcite samples collected from the hanging wall and foot wall of this fault-controlled cavern. For example, samples DH-11 and DH-2, obtained from the hanging wall, are white to yellowish-white and have little or no banding. In contrast, samples from the foot wall or from upward-facing surfaces are prominently and finely banded. One such sample, DH-7, has bands that vary from light to dark gray and from orange to dark brown and yielded alpha-spectrometic $^{234}\text{U}/^{238}\text{U}$ ages progressing (lower surface toward upper surface) from 520 to 100 ka (*4*). Thus, DH-7 records a rain of dust likely to have scavenged the bulk of the water-generated ^{230}Th during the time of DH-11 growth.

The character of the aqueous environment and the petrology of the vein calcite at Devils Hole argue against the likelihood of significant transfer of water-generated ^{230}Th to the environment of the DH-11 core. Direct measurements of the magnitude of the ^{230}Th-excess mechanism proposed by Edwards and Gallup demonstrate that this mechanism has not been effective during the past 60,000 years. Therefore, the implications of the DH-11 dates (*2*) remain.

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Social Learning in Invertebrates

G. Fiorito and P. Scotto (*1*) find evidence of observational learning in *Octopus vulgaris*: octopuses that observed a conspecific attacking a stimulus learned faster than did those directly conditioned to the task. Although this study may show some evidence for imitation by observers (a conclusion complicated by the observers' preference for attacking a red as opposed to a white ball), it gives no unequivocal evidence for observational learning.

In the experiment, demonstrators were trained through direct conditioning [(*1*), p. 545] to attack one of two colored balls (*2*). Observers then watched demonstrators attack that stimulus with no contingent reward or punishment given to the demonstrator; when observers were exposed to the two balls, they only attacked the same-colored ball that was attacked by the demonstrator. If associative learning was involved in this experiment, one might reasonably expect (i) that having seen the conspecific attack a stimulus object without contingent reinforcement, the observer would likely be reluctant to engage in a similar waste of energy (3) and (ii) that motion toward the previously observed nonreinforced stimulus would be inhibited (4) as one might expect if there were latent inhibition of stimulus preexposure. But *Octopus vulgaris* attacked balls with no shaping of the behavior required, continued to attack throughout extinction training, and made fewer "errors" than directly trained demonstrators.

Was this experiment a demonstration of observational learning or of rapid imitation? Appropriate strategies have been developed that distinguish between these forms of learning (5) and that assess the relative contribution of associative factors in the different stimulus elements present in the performance of demonstrators. A control experiment should have been performed in the study by Fiorito and Scotto to separate the role of stimuli from that of demonstrator (6). Even more essential, the possibility that species-specific behavior or imitation could account for the data should have been eliminated before the conclusion was drawn that "observational learning" in invertebrates "appears related to the cognitive abilities of the animal learning system" [(1), p. 546] had occurred. Octopuses visually track moving objects but are reluctant to attack novel stimuli (7). In the study by Fiorito and Scotto, perhaps the octopuses tracked the movement per se of (demonstrator) conspecifics and in so doing were inadvertently "directed" to the appropriate discriminandum. If so, Fiorito and Scotto show only that observers are less inhibited in approaching the more familiar of two targets; further experiments would have to be done to isolate the role of the conspecific in such training.

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The excellent study by Fiorito and Scotto (1) is the first to report observational learning in an invertebrate (*Octopus vulgaris*), but the authors do not provide a theoretical basis for the phenomenon. We point out that there is a general explanatory learning mechanism (2) that can account for observational or social learning, as well as for different learning phenomena in many species.

The report by Fiorito and Scotto joins a growing number of vertebrate studies (3) that isolate observational experience as a factor that is critical to the occurrence of learning by observers. Fiorito and Scotto also show (1) that learning by observation is strong, remarkably permanent, and apparently develops faster than learning by traditional Pavlovian and operant conditioning procedures. Observational learning, however, is not an explanatory learning mechanism; it is a learning phenomenon that is, itself, in need of explanation.

Fiorito and Scotto discuss (1), but quite rightly do not invoke, the imitation-by-copying model (4) as an explanatory learning mechanism for the behavior of observer octopuses. Imitation by copying does not fully account for their results (1) because it implies that observer behavior, following observation of a model, will replicate and match the model's responses (4). However, in this case, both the successful imitative responses and the incorrect responses made by the observer octopuses had the same form as the responses made by the demonstrator octopuses: attack and consummatory behavior directed at a stimulus object. The observer octopuses learned *which* stimulus to respond to, not *how* to respond to a stimulus.

One of us (M.D.S.) recently elucidated a learning mechanism, termed "releaser-induced recognition learning" (2, 5), which provides the study by Fiorito and Scotto (1) with an appropriate theoretical framework. According to this model, contiguous presentation (temporally or spatially) of two particular stimuli to an animal can change how the animal will respond to the stimuli during subsequent exposures if one stimulus is an unlearned releasing stimulus for a specific behavior and the other, initially, is behaviorally neutral. The effect on the animal is to induce transfer of control from the unlearned releaser to the neutral stimulus. This transfer may occur for many reasons, including (i) temporal factors: the neutral stimulus designates the arrival of the innate releaser; (ii) spatial factors: the two stimuli emanate from the same place; (iii) kinetic factors: movement by the releasing stimulus is directed at the neutral stimulus (as, for example, in feeding); and (iv) facilitation by novelty: the neutral stimulus is the only prominent, unfamiliar stimulus in the setting.

According to this releaser-induced recognition model (5), the feeding behavior of a demonstrator octopus (1) is an unlearned releasing stimulus for the feeding behavior of an observing octopus. Control over the release of feeding by the observer, however, is transferred from the stimulus features of the demonstrator's responses to the stimulus features of the food. The transfer of control is relatively permanent. As Fiorito and Scotto note (1), no reward or reinforcement is required for learning to occur.

The releaser-induced recognition model also accounts for other forms of social learning in which the demonstrator's and observer's behaviors are quite different and thus inexplicable as imitation by copying. Among vertebrates, alarm calls or food signals by demonstrators selectively release avoidance or approach behavior in observers (5, 6). We recently discovered a similar example in molluscs (7). In our experiment, the feeding behavior of freshwater snails was regulated by food pheromones released by feeding conspecifics. Hungry snails, exposed overnight to effluent from conspecifics (visually absent models) feeding on a novel food, approached or avoided that novel food depending on the density of the feeding snails that produced the effluent. Too few feeding snails (0 to 4) produced no preference toward the novel food, an intermediate number (8) produced attraction, and too many (16) produced aversion. Demonstrators responded to the novel food by feeding and modulating their release of feeding pheromone. "Observers" later displayed nonmatching learned behavior: the snails approached or avoided the novel food cues. Thus, imitation by copying appears to account for only a limited part of the evidence for learning based on social interactions (that is, studies in which observers replicate the demonstrators' responses). However, studies of both vertebrates and invertebrates reveal the existence of a more general and much simpler social learning process that is consistent with the releaser-induced recognition learning model (*7*).

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Response: We welcome the opportunity to discuss the theoretical framework of our study (*1*) on the copying behavior of the mollusk *Octopus vulgaris*. We found that an untrained octopus, after observing a demonstrator conspecific that had learned a simultaneous discrimination task (*2*), attacked the appropriate object five times consecutively without showing significant changes in its behavior. For the demonstrators, 17 trials for the "red ball group" and 21 trials for the "white ball group" were needed to reach the criterion of six consecutive successes; only four vicarious trials were needed for the observers to behave correctly 90% of the time. Our experimental design did not address the question of facilitation; all the learning occurred during the four observational trials, and because there was no contingent reward or reinforcement during the five testing trials, there was no facilitation of subsequent learning (*3*).

According to definitions used by others, it is possible that our experiment involved "rapid imitation," or a "species-specific response," or stimulus enhancement; but we maintain that observational learning did occur. Copying by octopuses occurred for both the color of preference (*4*) and for the other color. The points raised by Biederman and Davey about "rapid imitation" are semantic; imitation is considered a form of observational learning (*5*). Behavior toward both colors was copied; therefore some learned responses to the stimulus must have been involved in the observational phase. However, we have evidence of behavioral changes in observers during the observational phase that could be considered local enhancement or responses to social facilitation (*6*). These events occur in concomitance with the demonstrator action (coaction), which is consistent with our hypothesis that observational learning is occurring. Moreover, observers placed in isolation after the observational phase showed postures and chromatic changes (*7*) that matched the behavior of conspecifics.

The comment by Suboski, Muir, and Hall addresses an interesting point, the lack of a universally accepted and discrete definition of imitative behavior within the social learning framework. The behavior we reported could be a result of a "releaser-induced recognition learning" mechanism. Demonstrator octopuses may use some fixed-action pattern that they exhibit only when they are attacking the conditioned stimulus (*7*). These "changes" in behavior may be "interpreted" by the observer animals. After the experiments, observer octopuses exhibited (in isolation) the same behavioral performance as they did during the experiments, including "vicarious" discrimination, even if they had been "unconditioned" to the task.

Biederman and Davey report that octopuses in the laboratory "are reluctant to attack novel stimuli." In our experiments, the octopuses were well adapted to captivity and were used when they were "ready to attack" (*8*). The behavior that they exhibit has been described as a species-specific "drive to explore" (*9*).

The specificity of octopus behavior shown during the discrimination task may give us a powerful tool for the analysis of the learning capability of this species and could provide insight into the behavior framework of the (direct or vicarious) learning process. The ability of octopuses to copy the behavior of a conspecific, labeled by us as "observational learning," needs further investigation. In our opinion, a strict classification of terms involved (as in the psychological literature) cannot easily be applied to these new findings.

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