Teacher's Guide for

BEHAVIOR of MEALWORMS

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E | elementary
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TEACHER'S GUIDE FOR

BEHAVIOR of MEALWORMS

Elementary Science Study

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PREFACE

The Elementary Science Study is one of many curriculum development programs in the fields of science, social studies, and mathematics under preparation at Educational Services Incorporated. ESI, a private non-profit organization, was established in 1958 to develop new ideas and methods for improving the content and process of education through the collaborative effort of scholars and educators.

Initial grants from the Alfred P. Sloan Foundation and the Victoria Foundation were followed by annual grants from the National Science Foundation, and ESS began on a small scale in 1960 to develop materials for teaching science from kindergarten through eighth grade.

Over one hundred people are actively involved in ESS at present as staff members, consultants, or supporting personnel. The scientists and teachers who join in the conception and design of the units of study are called developers. Among these are biologists, physicists, mathematicians, engineers, and teachers representing every level of public and private education from the nursery school through the university.

Besides developers, the staff includes equipment designers, artists, and editors and utilizes the full resources of ESI—the film studio, the photographic laboratory, and two design shops for developing equipment prototypes.

All developers take their ideas and materials into classrooms where they try to iron out the technical, creative, and pedagogical problems that emerge as each unit takes shape. In one sense, the most important developers are the children involved in this early work. They are hard taskmasters.

ESS units are now being taught all over the United States and in some foreign countries. The role of ESS in several school systems is an active one, and these school districts serve as growing-points from which our ideas can expand to new areas. Teachers join in the experimental summer schools which ESS administers in conjunction with local school systems; other educators visit during the year. Some join ESS for a time as staff members or consultants. Those who return to their home districts help introduce ESS materials to their colleagues.

In addition, ESS is working with various school systems and schools of education in consultant and advisory capacities. ESS conducts frequent workshops and seminars with pre-service and in-service teachers and with administrators, in order to develop more effective training techniques. Staff members take part in national and regional meetings of educators and scientists.

Through the ESS Newsletter and other publications ESS is in touch with thousands of individuals and institutions.

The Elementary Science Study is an enthusiastic participant in the changing climate of education today.

FOREWORD

This unit, *Behavior of Mealworms,* is an outgrowth of the thinking, teaching, and learning of many people in many capacities. It has been developed, used, criticized, and refined in response to the experiences of teachers and children in a wide variety of classroom situations.

In an early stage, the study of mealworm behavior was part of a much broader unit on animal behavior. Classroom use, however, indicated that a unit on mealworms alone would be practical and would focus sharply on the major objectives of this type of elementary science content. My own experiences in teaching, for example, revealed that children could find out a surprising amount about mealworms by making careful observations and performing simple experiments. Further, through such observation and experimentation the children developed significant sophistication about how to approach a problem, about interpreting and evaluating data, and, in general, about scientific inquiry.

Behavior of Mealworms was first published by ESS as a twelve-page pamphlet in 1962. Many improvements were suggested by the teachers who used this early version. Principal among these was Mr. Donald Ford, who taught the unit many times. Other teachers who were especially helpful were: Mr. Larry Bramhall, Mrs. Laura Heller, Mrs. Susan Jorgensen, Mrs. Barbara Ragle, Miss Virginia Strong, and Miss Althea Weldon.

In 1964 a second experimental edition was published. For advice and encouragement in the preparation of that edition I thank many members of the ESS staff, particularly Miss Eleanor Duckworth, Mrs. Phylis Morrison, Dr. Roger Payne, and Mrs. Mary Lela Sherburne. In addition I am grateful to: Dr. Roger Payne and Dr. Richard Taylor for help with the Appendix, Mr. George Cope and Mrs. Muriel Williams for taking the photographs, Mrs. Betty Sears for doing the art work, and Mrs. Eleanor Sylvestor for supplying mealworms.

The fifty teachers who used the 1964 edition contributed many ideas to this present edition. The three directors of the Elementary Science Study, Dr. David Hawkins, Dr. Benjamin Nichols, and Dr. Charles Walcott, contributed invaluable support.

Finally, I would like to thank my friends, the mealworms. These diminutive creatures performed in all the experiments without complaint or pay.

David Webster
Elementary Science Study

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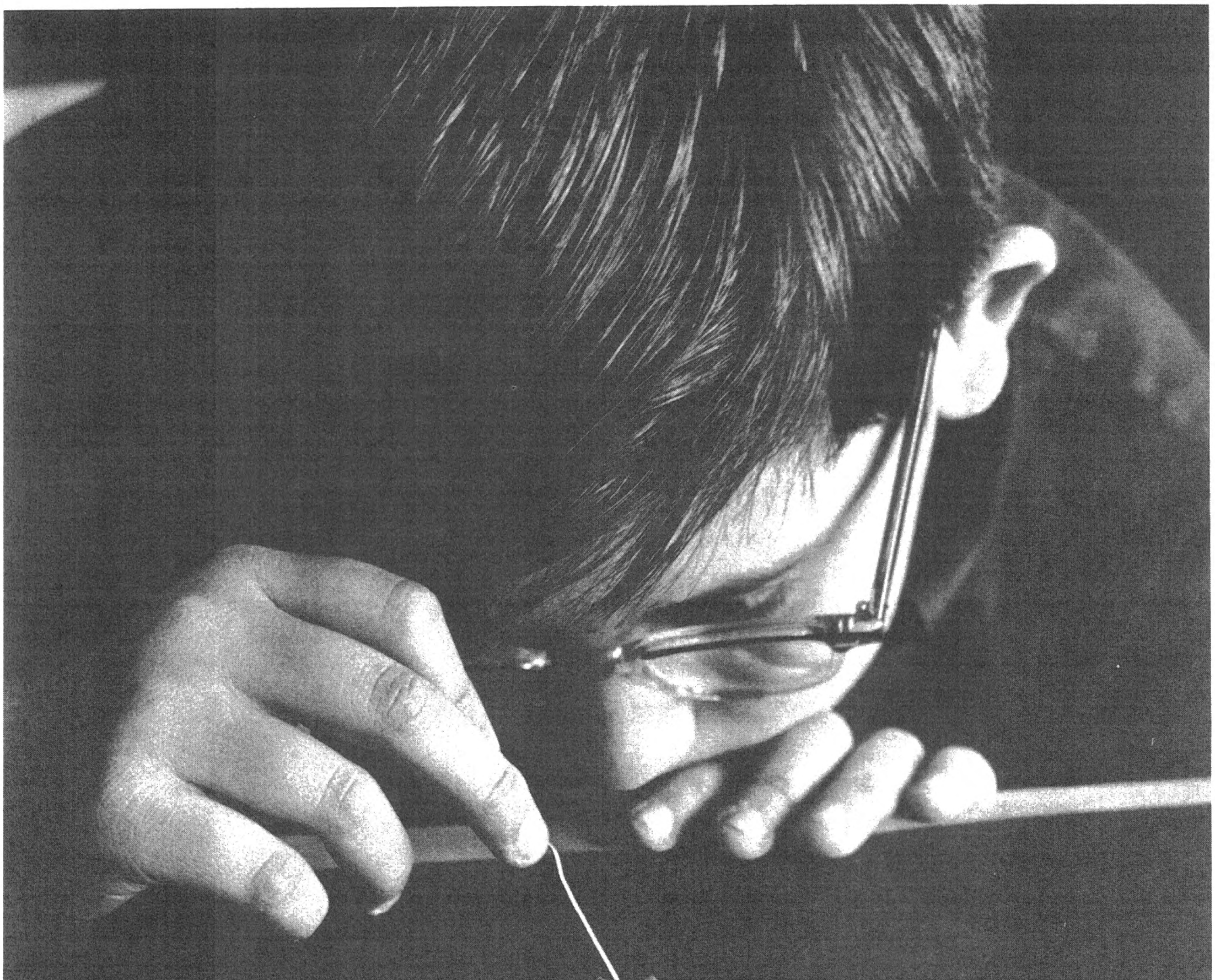


INTRODUCTION

Behavior of Mealworms stimulates children to ask questions about the observable behavior of an unfamiliar animal and then directs them to ways of finding answers for themselves. As children observe and experiment, they learn some things about the process of scientific inquiry and about the sensory perception of the mealworm. How to carry on an investigation is the most important thing that children learn from the unit; the factual knowledge about mealworms is comparatively incidental.

The pupils begin their study of mealworms with undirected observations that lead them to elementary experiments on mealworms. A multitude of questions arise, such as these: Can a mealworm see? How do mealworms follow walls? How do they find a pile of bran? How can a mealworm be made to back up? In their attempts to solve these problems, the pupils devise experiments, observe, measure, keep records, design and build equipment, and draw conclusions. As they go on, they usually become aware of difficulties resulting from their inability to control pertinent variables. After studying *Behavior of Mealworms,* children may realize that they still don't know much about the animal which at first seemed so simple!

For beginning studies of animal behavior, a relatively simple organism is essential. Mealworms are almost entirely unaffected by the artificial conditions of the classroom, and they exhibit reasonably consistent and definite behavior. Since little information about these creatures is available in nonspecialized literature, pupils must rely on their own evidence. Mealworms are convenient subjects for experimentation both in school and at home, since they are clean and odorless, require practically no care, and can be purchased very inexpensively from a number of sources.

Behavior of Mealworms has been taught most to sixth grade classes. If the unit is used in lower grades, the activities must be shortened and simplified. It is not necessary to explore all the activities described in this guide. If you spend a lot of time on the early experiments, your students may lose interest before you can complete the remaining activities. To cover everything, you will need 25-30 class periods for a sixth grade class.

Behavior of Mealworms can be thoroughly enjoyable and worthwhile for you and your students. You can, and should, leave much of your usual task of teaching to the mealworms. These small, crawling creatures can be the means through which your students learn a great deal about the techniques of scientific research.

DISCUSSION *of* ACTIVITIES

1. Watching Mealworms

The study of mealworms can begin by having students watch them. This undirected activity provides background for the more refined observations and experiments on mealworm behavior which come later.

The First Assignment

The children can be shown the mealworms and told they are going to watch some at home to see what they can find out about them. Their observations should be written down. A chart might be used with the headings "What I Did" and "What The Mealworm Did." Drawings might also be made.

Two or three mealworms and some bran or dried cereal flakes can be transported home in a wax-paper sandwich bag that has been folded over and stapled at the top. Mealworms can also be carried inside drinking straws. Suggestions for the proper care of mealworms at home should be reviewed with the students. Information of this nature can be found in Appendix II. (See pages 43-46.)

Although children are not usually intentionally cruel, they might be cautioned not to do anything that might injure the mealworms. One restriction could be that no one does anything to his mealworms that he would not like done to himself. Since a mealworm has chemical receptors over its entire body, putting a drop of turpentine on a mealworm is somewhat like having turpentine poured into one's mouth or nose. Irritating liquids should be dropped near but not directly on the mealworms.

Usually parents allow mealworm experiments to take place at home. Sometimes they even become involved in the work themselves. You might want to send a note home asking parents to cooperate.

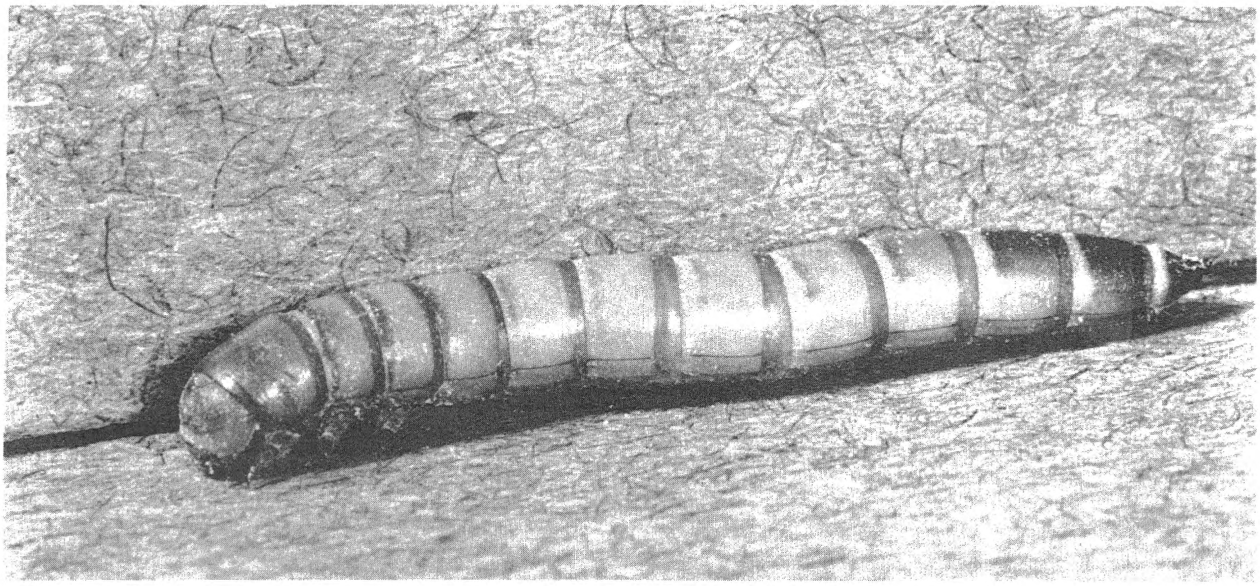


FIGURE 1. Enlarged Photograph and Labeled Diagram of Mealworm.

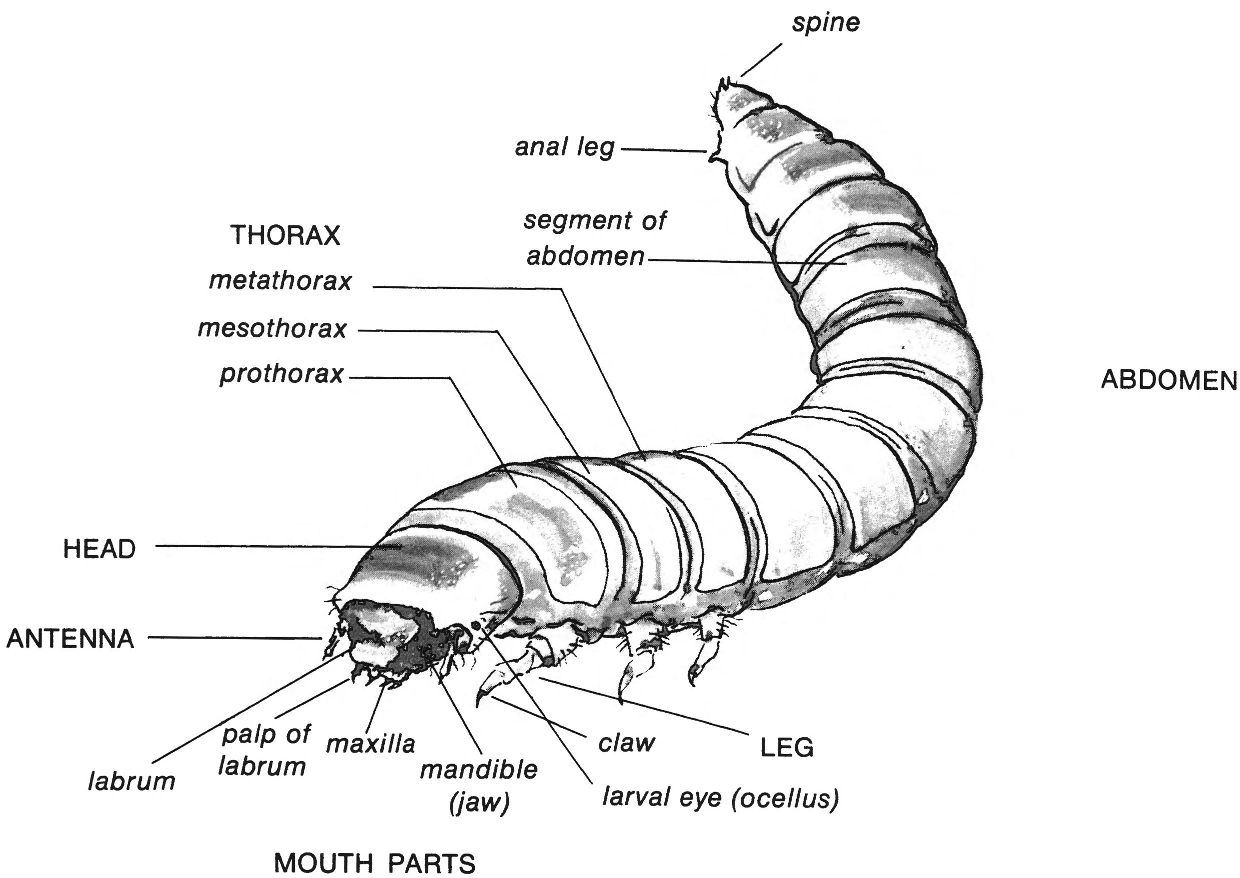
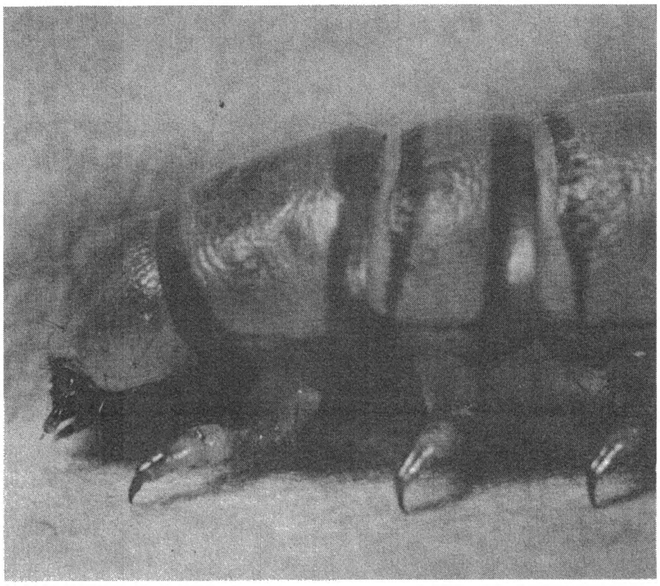
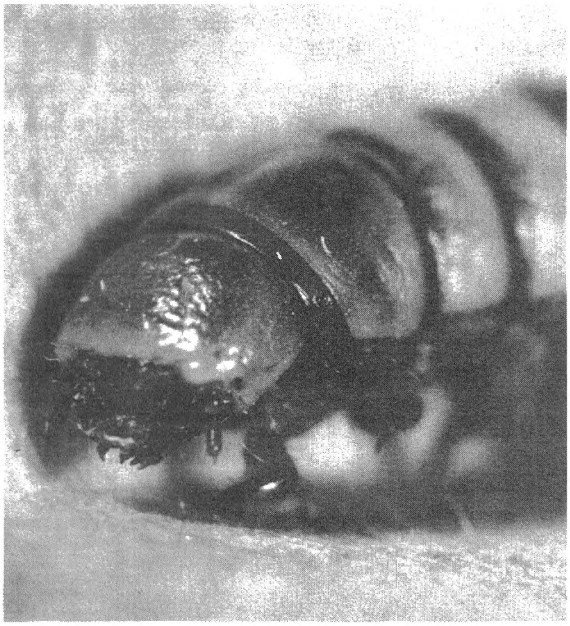


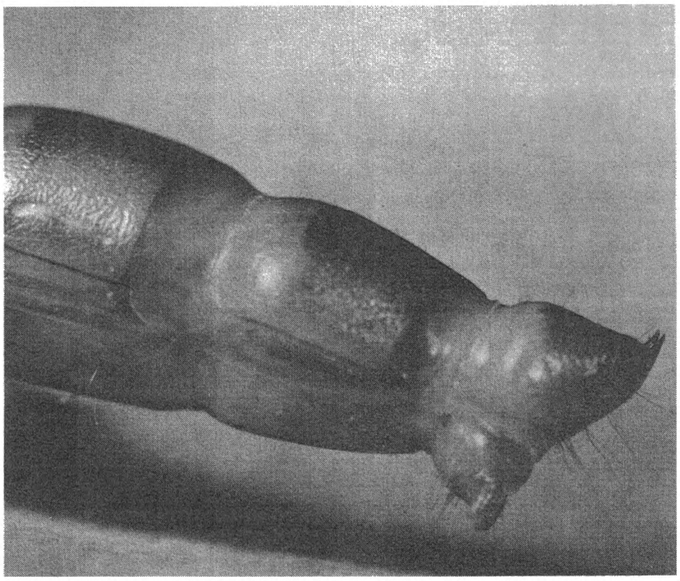
FIGURE 2. Photographs of Mealworm.



Front of mealworm, showing leg structure.



Front of mealworm, showing details of head.



Hind end of mealworm.

Examples of What Children Do With Mealworms

After watching their mealworms at home, the children have usually made a great number of varied observations on the structure and behavior of their mealworms. The following are some examples of what can be expected when these observations are reported in class:

“I dropped vinegar on his tail and he didn't like it.

Mealworms are usually quite lazy.

They ride on each other's backs.

They can't walk well on smooth surfaces.

If you lay a pencil on a mealworm's back, it's like someone hit you in the back with a baseball bat.

When I touch one of my mealworms he bends his tail. This is how I tell them apart. One bends and the other doesn't.

I held my mealworm on a string out the window.

I shined a flashlight on him and he crawled away.

A mealworm's body has 13 segments.

He backs up when he comes to another mealworm.

He turns like a bulldozer. The legs on one side stop.

He always moved away from any intruding hand or object. This was probably instinct.

They never stay in a group for a long time. He is sort of an individual.

I put mine on different colors, but it kept falling off. It never learned.

I stuck him in a balloon and blew it up.

Mealworms are always searching for open doors in a box.

They have rhythmic leg motion.”

Much fault can be found with many of these observations. Some of the things which the children do appear senseless. What did the child expect to learn by dangling a mealworm out of the window or by sticking one in a balloon? Students often draw conclusions from their observations, but usually their inferences are based on evidence which is most inconclusive. The wiggling of a mealworm in a drop of vinegar seemed to indicate to some child that mealworms do not like vinegar. Children look at mealworm behavior in terms of themselves. A mealworm walking around the sides of a box was trying to find an open door so he could get out. Mealworms are even lazy!

Significant observations in the list of examples are those that deal with structure, locomotion, and a response to a certain stimulus. These are good because they lead to questions which can be explored further by the students. Anatomical characteristics like six legs, two antennae, a head, 13 segments, and some tail bristles are usually noticed. (See Figure 1.) So is the stepping pattern of a mealworm's legs, which often depends upon the mealworm's speed and direction.

Suggestions for Conducting the Discussion

One class period, or perhaps several, can be devoted to having students report their findings. The discussion should move freely and go in the direction given it by the children. You can ask questions to help elicit comments about what was observed. "Do you think mealworms can see?" "How are mealworms different from earthworms?" "Are mealworms very smart?"

Often the best discussions occur when children debate some differences of opinion. If situations like this do not arise spontaneously, you may be able to create them. "Did anyone else see something different from this?" Controversies can often be resolved by having the children take another, closer look at mealworms in school or at home. Sometimes the additional evidence will still not end the disagreement, and the question must be left unsettled, at least for a while. You may feel uneasy about leaving questions unanswered, but this does not usually seem to bother children.

You should remain alert for observations which might lead to further experimentation by interested individuals. For example, one student could tell her mealworms apart by tail curling. "Can anyone else find a way to tell his mealworms apart?" The question of intelligence may come up, as it did once with the mealworm which never learned not to fall off the different colors. "Can a mealworm learn anything?" "Could one be taught to walk through a maze?" (See Appendix IV, pages 53-57.)

No attempt should be made to correct misunderstandings that emerge during discussion. It is doubtful that any amount of talking at this time would be of much help. This is the main purpose for having the children do the activities of the entire unit: to teach them how to experiment, observe, and draw conclusions. This takes a lot of time. Children learn this best by going through the activities in the unit.

2. Optional Experiments on Walking and Eating

Before proceeding with the activities described in the sections which follow, you may want to spend several days investigating how a mealworm walks and eats. Some of the experiments suggested below could be studied by your entire class, or by only those students who want additional work.

Walking

The method of walking is almost always described by someone. In what order does a mealworm move its legs? Three children standing in a row could demonstrate different ideas with their three pairs of legs. (See Figure 3.) An easier way to see how a mealworm walks is to watch it on a mirror, or from underneath a piece of glass.

You could ask your students other questions about locomotion, such as:

"Does a certain mealworm turn more often to the right or to the left?

Can you make a mealworm go in a straight line?

How does a mealworm walk on the moving turntable of a record player?

How far does a mealworm go in a minute?

How fast can the fastest mealworm go?

How fast does a mealworm dig down through bran?

If placed on a slant, do mealworms walk up more than they walk down?

Why do mealworms sometimes walk backwards? Do they back up every twentieth step? Can a darker spot or speck of dirt be found at the place where the mealworm goes backwards?"

Eating

Do mealworms eat bran? A few flakes of bran can be placed with a mealworm in a tiny closed box, like a match box. If the bran disappears, it has probably been eaten. Two

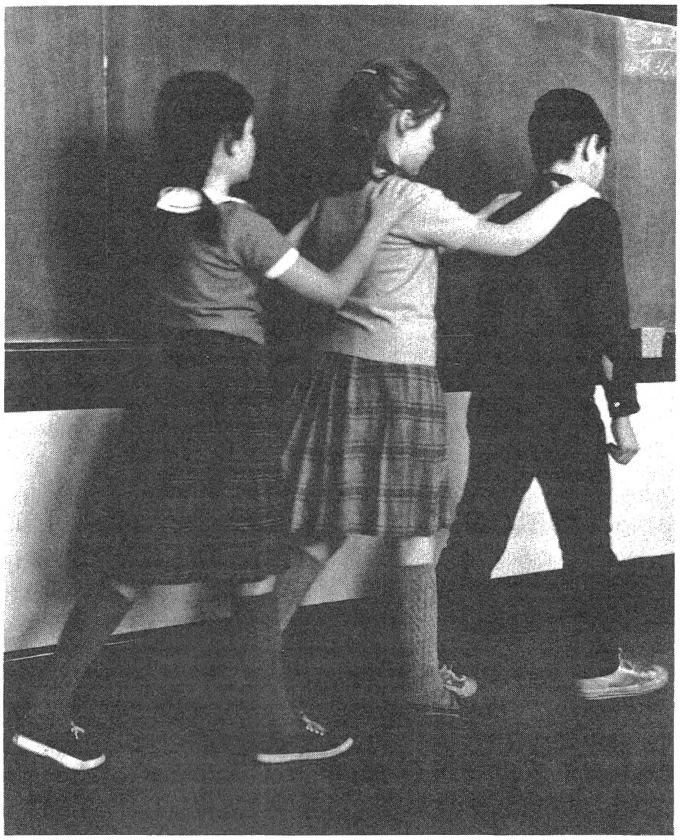


FIGURE 3.
Children Demonstrating Different Ways to Walk with Three Pairs of Legs.

boys in Seattle computed the weight of food consumed by a mealworm:

"*We put three mealworms in a small box. I crumbled two flakes into pieces in the box. At the end of each school day, I estimated about how much of a flake they ate. At the end of four days the flakes were just about gone. They ate about one half a flake a day. The mealworm eats approximately 1/6 of a flake a day. In grams the mealworm eats 1/30 gram per day, 7/30 gram per week, and one gram per month.*"

Other food, such as different kinds of breakfast cereal flakes, could be offered to mealworms in this way to see if it is eaten. One teacher wrote:

"*The children reported that mealworms particularly liked Rice Chex and jelly, but got stuck in the jelly and had to be pulled out. They also seemed to like carrot and potato peelings, Captain Crunch cereal, and Wheaties. They positively did not like dry dog food (Gravy Train) and baby food.*"

Would mealworms raised on corn flakes, for example, prefer bran or corn flakes? Food preferences might be determined by giving several kinds of food at once.

A science supervisor in Seattle conducted some experiments on the water requirements of mealworms, and reported:

"*Somehow I couldn't believe that this dry stuff could provide them with the moisture that we somehow feel all animals need. The experiment I tried certainly didn't prove they need water, but it proved to my satisfaction that they wanted it. I took some of those double-ended cotton swabs called Q-tips, moistened one end and put them on top of the food. In a little while the moist end looked like the head of Medusa, and the dry end attracted nary a worm. Soon the moist end was shredded and torn; the dry end appeared untouched.*"

NOTES

3. Can Mealworms See?

Students usually become aware of the mealworms' tendency to follow walls. A question which follows naturally from this observation relates to the way in which mealworms do this. If they follow walls, they may have some way of sensing the wall's presence.

See if your children can explain how the mealworm might be able to perceive a wall. Should they lack ideas, you could ask them to think of ways they themselves would have of walking along beside the wall of the schoolroom. One way would be to use one's eyes, as might a mealworm. But suppose the person were blind or it were dark? A child can be blindfolded and watched as he follows the walls of the classroom. Perhaps an arm or leg is dragged along the wall. What could a mealworm use to do this?

Looking at Mealworms

A careful anatomical examination at this time might reveal some organs of sight or touch. Mealworms kept in a jar on top of some ice will become sluggish and therefore easier to examine—until they warm up. Magnifying glasses and microscopes could be used if they are available. Students often say that a mealworm looks like a monster when seen through a microscope. They might make drawings to show details of structures they find on the mealworm's head and body. (See Figure 4.) The drawings could be labeled to indicate the possible functions of the different parts.

When the children have found what they can on their own, they could study photographs of mealworms. For this purpose enlarged copies of each of the illustrations shown in Figures 1 and 2, pages 3-4, have been reproduced for purchase with this Unit. You may want to mount them on cardboard before making them available for your class to study.

After they have combined direct observation with study of the photographs, the pupils probably will have seen the pointed antennae, the hooks on the end of each leg, the black, eye-like spots on the head, and the fine hairs on the legs and sides of the body. One or more of these structures could serve as a wall-sensing device. The function of the so-called "eyes" of a mealworm could be compared with those of other animals. "How are a mealworm's eyes different from yours?" "Do you think a mealworm can see as you can?" The evidence on sight may be contradictory, since mealworms bump into things but do seem to respond to bright lights. "Is it possible to 'see' just light and dark?" A large box could be lowered

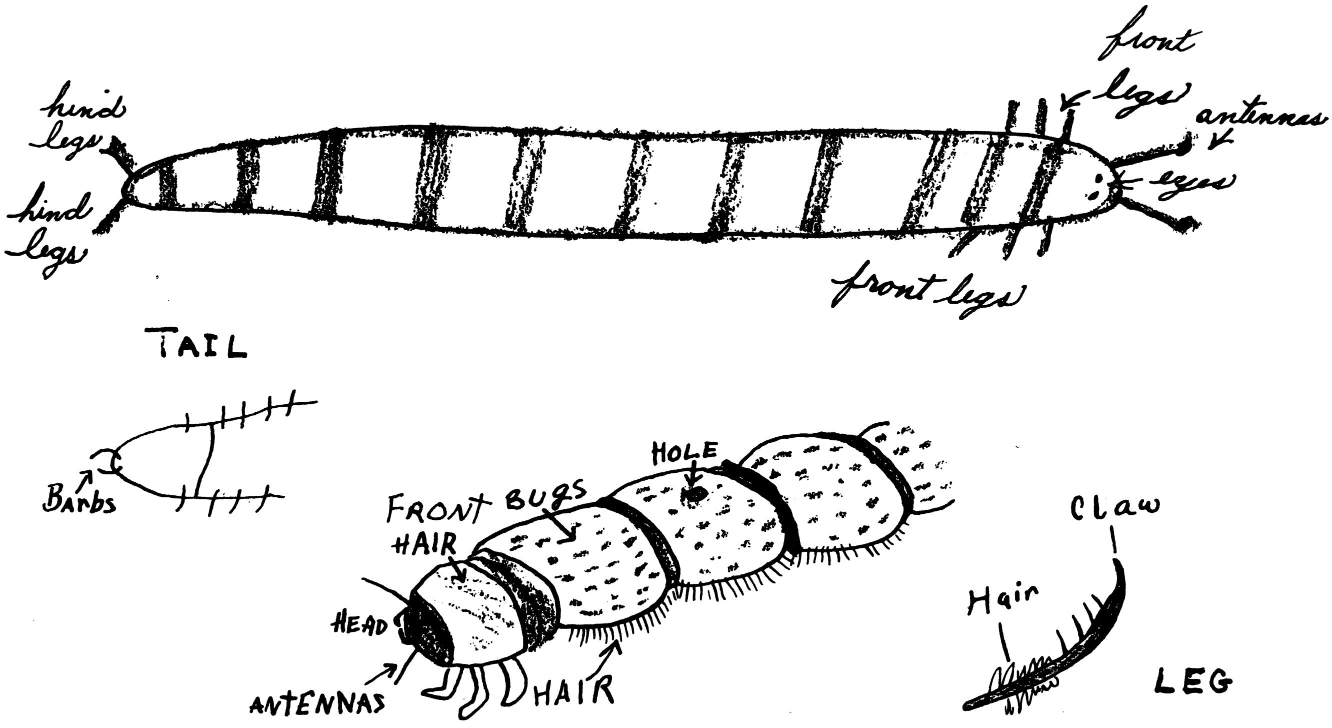


FIGURE 4. Students' Drawings of Mealworms.

over the head of a child with his eyes closed. He can't really see, but he is still able to tell when it becomes darker as the box is lowered.

How Can Mealworms Follow Walls?

"What can we do to find out which parts of the body might be used by a mealworm for following walls?" The children might suggest that, to test sight, a mealworm's head could be coated with nail polish or black paint. This may be a good idea, but it should be discouraged since it is harmful to the mealworms and does not show much anyway. A magnifying glass could be used to look at the legs or antennae of a mealworm which is following a wall.

"Would a mealworm still be able to follow a wall in the dark?" Let your children try to work out some techniques for answering this question. The problem, of course, is how to see where the mealworm travels in the dark. If chalk dust or talcum powder is sprinkled on the bottom of the box, mealworm tracks made in the dark can be observed.

In the words of one student:

"To find out whether mealworms use their eyes or not we put them in a dark box with flour on the bottom, hoping that the worm would leave tracks showing where he went. It did not work because if there was enough flour for tracks, he would just bury himself and do nothing. If we used too little for him to bury in, it wouldn't leave tracks. What I think should be done is to put the mealworm in a box in a pitch dark place

with a fluorescent dot of paint on him. Then we can follow his movements. **"**

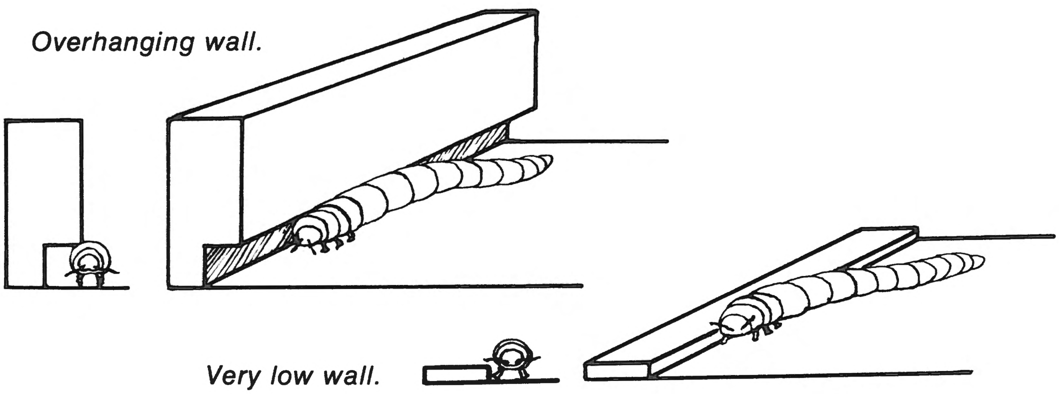
In spite of what this student says, a mealworm's path can plainly be seen if the powder is not too deep.

Building Walls for Mealworms to Follow

Building a variety of "mealworm walls" is another worthwhile activity. The idea can be introduced by the teacher if it does not evolve naturally. "What kind of wall could you build to see if mealworms follow a wall by seeing it?" "Maybe you could make one which the mealworm could not see. How could this be done?" "What would it mean if a mealworm could not follow a glass or clear plastic wall as well as a smooth and opaque one?"

"What kind of wall could be made to show if a mealworm follows a wall by dragging its legs or body along it?" See if the children can figure out some ways to make such a wall. To keep the mealworm's protruding feet from touching, a wall could be made with an overhang. A very low wall would allow only the feet to come in contact with the vertical surface. (See Figure 5.)

FIGURE 5. Diagrams of Walls for Mealworms.



"What does a mealworm do when it reaches the end of the wall it is following?" "Does it continue straight ahead while its tail is still in contact with the wall?" If it does, this could mean that the wall is sensed by the tail. Perhaps the mealworm will cease following the wall after its head passes the end. What might this indicate?

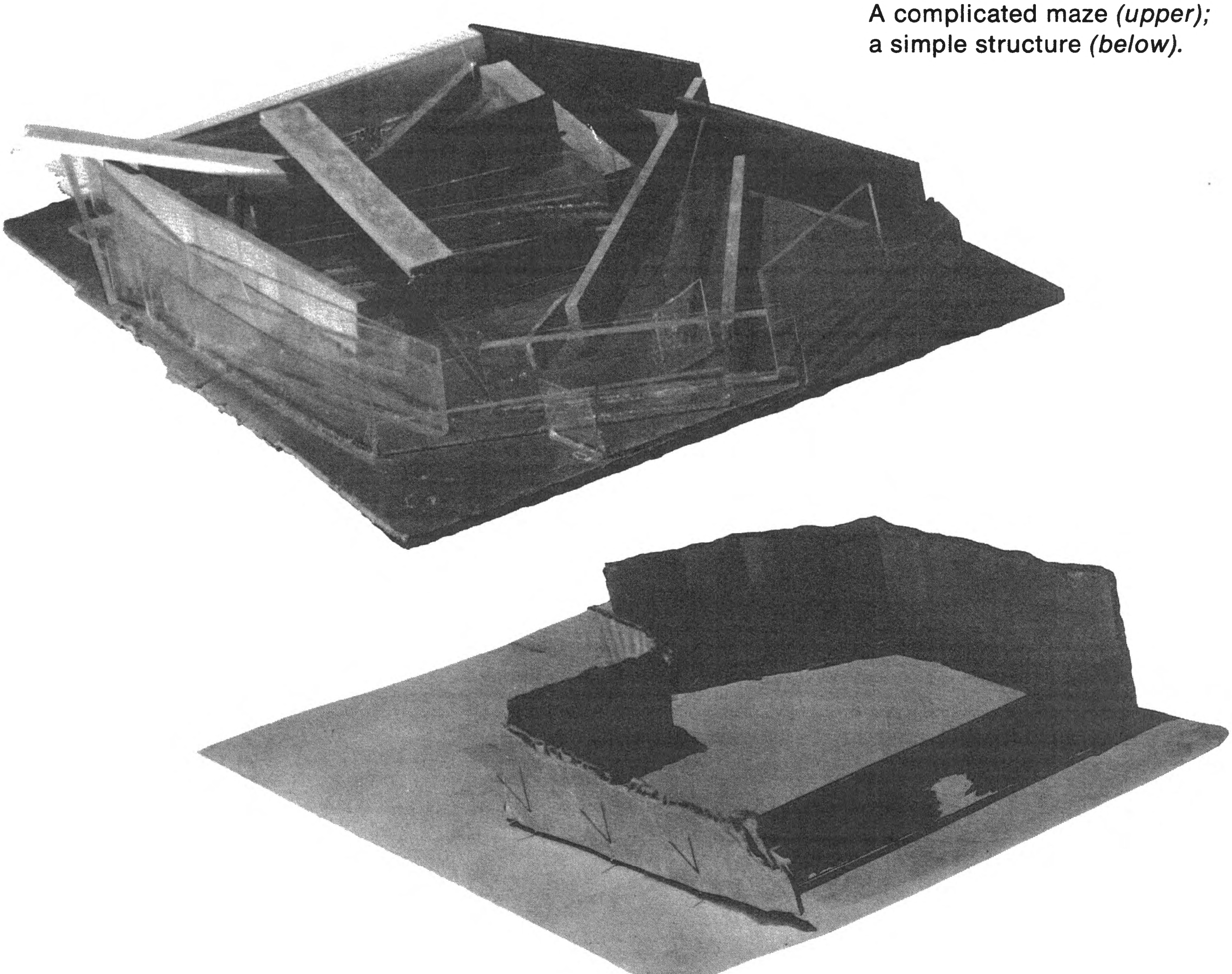
"Can a mealworm detect a 'negative' wall (an overhanging edge)?" "Will it slow down when coming to a cliff?" "Does a mealworm walk along a precipice just as it walks along a wall, or does it fall over?" "Can a mealworm follow a wet wall better than a dry one?"

With the foregoing in mind, the construction of test walls can be carried out by the students at home or in school. If done in school, the necessary materials should be provided. Match sticks, toothpicks, popsicle sticks, paper clips, and tongue depressors can be used. Pieces of cardboard and plastic can also be cut up. (See Appendix I, page 41.) The walls can be built inside boxes or on separate pieces of cardboard. They can be held together with glue and left to dry before the mealworms are put in.

Students should keep in mind why they are making their walls. This exercise allows children to design and make equipment to test "hunches" they might have in explanation of wall-following. Often the array of materials leads some children to make elaborate structures with little apparent purpose. Walk around and ask, "Why are you making your wall that way?" Perhaps materials should be limited so there is no opportunity to construct more than is necessary.

In one trial class almost everyone made a complex obstacle course similar to the one shown in the upper photograph in Figure 6. One girl, however, built an effective set of walls very simply. As the lower picture in Figure 6 shows, one side was

FIGURE 6.
Walls Made by Students:
A complicated maze *(upper);*
a simple structure *(below).*



made with a piece of plastic, blackened with a crayon in all but one place. "If he can see, he'll try going through the clear part," she said. Another side was a piece of cardboard with a number of holes punched in it. "If he feels with his antennae, he'll get confused." Pins stuck through the bottom of the third side held the cardboard just off the ground so there was a crack under it. "If he feels with his feet, he'll try to go underneath."

Reporting the Behavior of Mealworms

Students enjoy watching mealworms walk along their new walls. Magnifying glasses can be used if they are available. You might wish to have the children describe their operations in a written report to answer the question of how mealworms follow walls. Many of their conclusions may be quite contradictory, but the important thing is that the conclusions be drawn from real observations.

"*I found out that the mealworm follows the wall with his legs, because I put the mealworm in the maze and it followed the wall by touching with the legs.*

I think they use feelers to follow walls, because they didn't seem to be using anything else and they kept touching the walls with them.

From watching the mealworms travel in and out of the maze, I found that they mostly follow walls with their bodies and not their eyes or antennae. I saw that when they followed the walls they rubbed their sides against the wall to tell if it was there.

At first I thought they followed walls with their bodies. But now I think they have eyes, because they tried to walk through the glass walls, but they didn't try to walk through wooden walls.

I don't think they can see, because they just bump into the walls of the maze. When the mealworm goes into a pointed corner, it doesn't know which way to turn.

By watching a mealworm in a maze, I found that mealworms have eyes in back of their body. I know this because I had a door that opened and closed. When he got to where he could see the door, the front part of him started to go the other way. But when his back saw the opening at the other end, he started to go towards it. Then I shut the door and he started to go forwards again."

4. How Does a Mealworm Find Bran?

This activity should be introduced by a demonstration one or two days in advance. The class can be shown a shoe box with a pile of bran at one end. About twenty mealworms can be placed in the other end and the box left uncovered. For purposes of simplicity the activity is described here using bran. Instead of bran, however, any dried cereal flake can be used.

By the next day the children can see that many of the mealworms are in the bran. Then pose the question, "How do they find the bran?" (or cornflakes or whatever cereal you have chosen to use). Some possibilities such as sight, smell, or just chance might be brought out in class discussion.

"How could we find out if mealworms find the bran because they sense it (by sight, smell, or otherwise) or just because they happen to bump into it?" You probably will have to suggest to the children that a useful procedure is to mark the mealworm's path with a pencil as it moves along. An aimless direction of movement might occur when the mealworm is first released in the box with the bran pile. But as the mealworm wanders closer to the bran, is a distance reached at which its motion becomes directed toward the bran? What would this mean? It might show that the mealworm could somehow detect the presence of bran from that particular distance.

To obtain uniformity and thereby permit better comparison of results, duplicate a paper on which is indicated a starting point for the mealworm and a circle for the bran. The design of this worksheet should approximate the positions of the bran and the worms in the original demonstration. Pupils can draw the mealworm's path by following it around this paper with a pencil. The students should be cautioned against guiding the mealworm's direction by pushing it with the pencil. A ruler can be held along the edge of the paper to keep the mealworm on the paper. Several trials should be made with each of several mealworms.

Circulate around the room as the pupils work. If interest lags, ask questions to encourage more experimenting.

❝ Does the mealworm seem to be able to go straight to the bran after he gets close?

Are mealworm paths different if there is no bran on the paper?

Does the distance traveled by a mealworm on later trials become shorter, indicating the worm is learning the location of the bran?

Suppose you made two piles, one along the edge and the other in the middle. Which pile would most mealworms find?

Would most mealworms go to a large pile of bran instead of a smaller one?

Does a mealworm go under a pile of bran more than it does under sawdust? (Pencil shavings from a pencil sharpener can be substituted for sawdust.)

What sort of paths would the mealworms make in the dark? (Use talcum powder.) ❞

One way to help students compare results is to make a composite of some mealworm paths. This can be done by transferring them from the student's papers with carbon paper or by eye onto a master sheet, which can then be duplicated or shown through an opaque projector. An example from one class is shown in Figure 7.

The conclusion which is usually drawn is that the mealworms' discovery of bran is by chance alone. This conclusion, however, was questioned by Professor Robert Christian of the University of British Columbia. He wrote:

❝ . . . the question is raised as to how the mealworms find bran. I'm skeptical about both conclusion and method.

First, I am impressed by the fact that all the mealworms found the bran eventually. And I find it hard to believe that some mealworms would starve to death if they had access to food but were merely unlucky. This thinking suggests the following experiment: suppose you substituted sawdust for the bran. Would all the mealworms find the sawdust? Would they find it as quickly as they find bran? What would the paths taken by the mealworms look like?

Next, I don't feel that the apparent random paths . . . justify the conclusion that the mealworms find the bran by accident alone. What if the mealworms could sense bran in some feeble non-directed way? Have you ever had the experience of wondering where some odor was coming from? Perhaps you could blindfold a child and have him locate a piece of paper

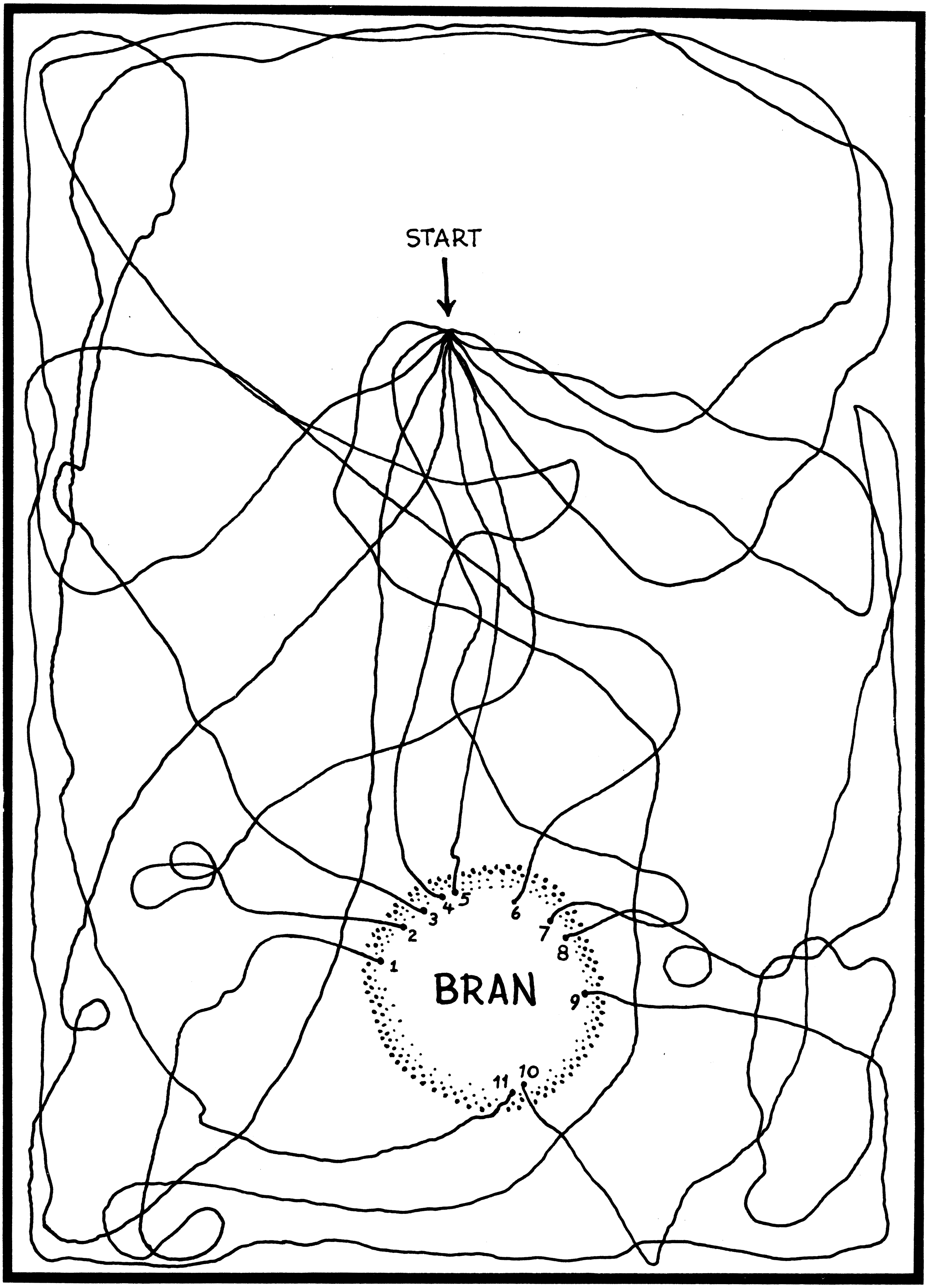


FIGURE 7. Paths of Mealworms in a Box with a Pile of Bran.

on which you had put a drop of perfume. I would guess that his path (in a large enough room) would be like the path of a mealworm finding the pile of bran."

You might want to read the letter to your class and see what they think about it. You could perform some of the experiments which Dr. Christian suggests if the children seem interested in pursuing this problem further. One teacher reported:

"*We read to the children the suggestion of blindfolding and locating odor, and they enthusiastically demanded to try it. Perfume on blotter paper proved to be too faint and even ammonia was not very noticeable. Nevertheless, the class enjoyed the experience. Some members of the class traced on the blackboard the paths of their human mealworms.*"

Finally, your pupils may be interested in another series of observations investigating the mealworms' behavior once they come in contact with the bran. Do any mealworms stop partway into the pile of bran, with their heads in and tails sticking out? Would they do this if the pile of bran was very small? What about a long, thin pile? How far into a big pile do they go? How do they know when to stop so they do not come out the other side? Do they keep going until they begin to come out, and then back up?

It might be interesting to discuss the design of a machine that would work like a mealworm—a machine that could be released at any place in a box and eventually come to a halt beneath a pile of bran. In what ways could such a machine and a mealworm be similar?

NOTES

5. Experimenting With Animals

Before the children proceed with more investigations of mealworm behavior, consideration should be given to some of the errors often made when experimenting with animals. (See Appendix III, pages 46-52.) To help accomplish this, students can criticize descriptions of a few hypothetical experiments.

Some examples appear below. It is not necessary to use all of these. You should try to write some of your own. Your students could even write one or two after reading a few. The children's descriptions of imaginary experiments could be exchanged among themselves and criticized.

1. Does my snake prefer to eat baby chicks or rats? I answered this question by putting a five-day-old chick in the snake's cage. My snake swallowed the chick in 10 minutes. The next night I put a four-inch white rat into the cage. The next morning the rat was still uneaten. My snake prefers to eat chicks rather than rats.
2. I wanted to see if mealworms went toward walls. I made the walls by putting six little boxes in a circle with spaces in between. (See Figure 8.) A mealworm was dropped in the middle, and a pencil mark was made at the spot where the mealworm touched a box or went out between the boxes. I did this 72 times, and 39 times it went to a box. I think mealworms walk to walls. (Unlike most of these exam-

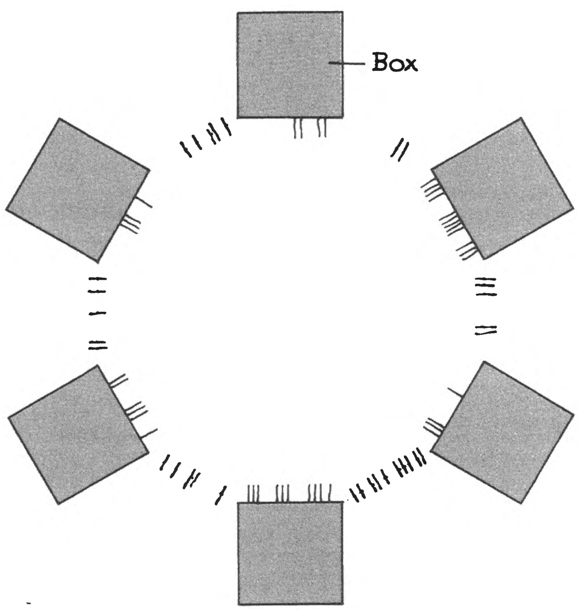


FIGURE 8.
Diagram of Results of Experiment to See if Mealworms Go toward Walls.

ples, this experiment has actually been done. You might want to have the children try this sometime.)

3. I tested my dog to see his reaction to music. So every night after his dinner, for two weeks, I put him in my room and turned on some music. On almost every night he was asleep within 10 minutes. It seems that music makes my dog go to sleep.
4. I wanted to find the effect of noise on a kangaroo. The noise was made by exploding a 2-inch fire-cracker 10 feet behind the animal. This was done ten times to each of five different kangaroos. I saw that sometimes after the "bang" the kangaroo jumped higher than usual.
5. I wanted to see if mealworms like high places. I put my mealworm on a book and raised it five feet above the floor. This was done about 25 times with several different worms. Every time except once the mealworm crawled around the book until he fell off onto the floor. It took from 8 seconds to 6 minutes and 15 seconds for this to happen. The one mealworm which didn't fall off just sat on the book and didn't move. I don't think mealworms like heights.
6. I have heard that bats get into people's hair. I found a bat and sneaked into my sister's room and let it loose. It flapped around the room three times and suddenly flew into her red hair and boy, did she scream! Now I know that this superstition is really true; if there are people around, bats will try to fly into their hair.
7. My problem was to find out if coldness would affect the behavior of June bugs. I put 20 fully grown bugs in a metal box 12 inches square with a cover. The June bugs ran all around the bottom of the box. Then I put 4 ice cubes inside the box at one end. After 10 minutes all the insects had moved to the end of the box away from the ice cubes. I guess that June bugs try to get away from the cold.

CHART 1. Temperature and the Sound of Crickets.

TIME	AVERAGE NUMBER OF TIMES CRICKETS MADE A NOISE IN A MINUTE	TEMPERATURE
2:00 TO 3:00 IN AFTERNOON	38	67°
9:00 TO 10:00 AT NIGHT	21	42°

8. Does temperature affect the number of times a cricket cricks? To answer this question, I used 17 adult male crickets in separate outdoor screened cages. Chart 1 shows my results. I have concluded from this experiment that temperature does affect the cricking of crickets.
9. I found out that mealworms prefer to live in Wheaties rather than sawdust. I made a small pile of both of these 6 inches apart, and placed a mealworm between them. In 52 seconds the mealworm had walked to the pile of Wheaties and disappeared into it. After one hour he was still under the Wheaties.
10. Do mealworms prefer a certain color? First, I cut four pieces of paper. The colors were red, blue, black, and yellow. I pasted the paper to look like this. (See Figure 9.)

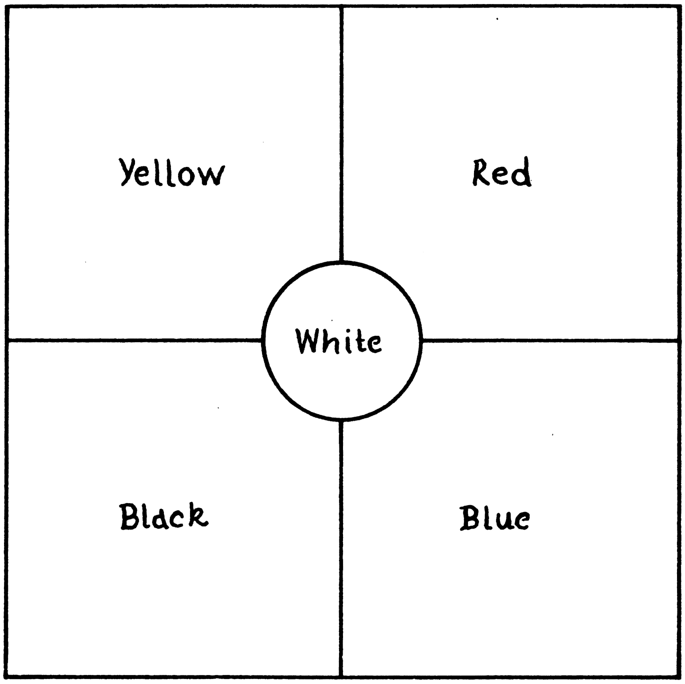


FIGURE 9. Diagram of Experiment to See if Mealworms Prefer a Certain Color.

Then I took five mealworms and set them in the middle of the paper on the white disk. And I watched to see where they would go. I ran 44 tests and at the end I tabulated these results:

Blue	Red	Yellow	Black
42	56	50	72

Two times a worm didn't move. It seems as if mealworms prefer black. I wonder if it's because black is warmer? (This experiment was reported by a student from Bickleton, Washington.)

The descriptions which you want to use can be duplicated and distributed. The children can be asked to tell in writing what is wrong with each experiment and how they would do it better. Discussion of their opinions in class should elicit a lively debate.

Some of the general criteria of good experimentation with animals which may come out of this exercise are given below. You should not give this list to the children.

1. In order to know if the animal is doing something different, one must first know its usual behavior.
2. An animal must be given a choice if it is to show a preference for one thing over something else.
3. What is done to an animal must be described in as much detail as necessary.
4. The description of what the animal does in the experiment must be as complete as possible.
5. The same experiment usually should be done many times.
6. The conditions should be controlled so that, as much as possible, the animal responds only to what is being tested.

NOTES

6. Making a Mealworm Back Up

The work on backing up gives the children a chance to observe how a mealworm reacts to various stimuli. Here they may begin to see how measurement by counting can refine qualitative observations. Because backing up is an obvious and clear-cut response, it is an easy one to begin with. Perhaps you or your children will find some other suitable question for study also.

Various Ways to Make Mealworms Move Backwards

If your students have ever seen mealworms backing up, they can probably describe examples of this somewhat unusual behavior. Then you can ask the question, "How many different ways can you find for making a mealworm back up?" Students can work on this problem at home and give their results in the following class.

The various methods which have been found to make mealworms back up should then be listed on the board. Some of the ways mentioned in trial classes are listed below:

flashlight
smoke
burning match
vinegar on Q-Tip
hot iron
loud noise
bumping into something
ammonia
water dropped on head
turpentine dropped with medicine dropper
touching with pin
electric shock with battery
touch with pencil
color
blowing on it through a straw
spinning on phonograph table
wet ink from felt pen

If the list becomes too long, it might be convenient to have the children group some of the similar ideas together into larger categories. In the list above, the use of vinegar, turpentine, and ammonia might be combined under the heading of odor.

Selecting the Best Way to Make a Mealworm Back Up

The question can be raised: "Which is the best way to make a mealworm move backwards?" Guesses can be heard, but there will probably be little agreement. "How can we find out which is best?" Some child may say that everyone should try all the different ways. "Would it be better if everyone tried each way more than once?" "Why?" Perhaps the students can be led to see the desirability of *quantitative results* obtained by testing each method a large number of times. They usually do not realize that this may permit more precise statements to be made about certain observations.

Some ideas for making a mealworm back up might be considered poor by a majority of the students, and these can be eliminated through discussion. The class should then select for more study the four or five methods it thinks most promising. You can suggest that a definite procedure be established to test each method.

One class had the following ideas for hot things to use in testing heat:

a piece of glass heated on the radiator
steam from a steam iron
a nail heated by a match
short circuiting a dry cell battery with a wire and wrapping the wire around the mealworm

The hot nail was selected because it was thought to be the most uniform source of heat and would be readily available.

Since the improper use of a hot nail can injure a mealworm, you could suggest that the heated nail be held far enough away so the mealworm would not get burned, but close enough so it could feel it. The children can experiment with one another to find what this distance would be for their own hands. Such a measurement may help to establish a practical distance, even though the small size of mealworms probably makes them more sensitive to heat than we are. A hot nail could burn a mealworm's sensory hairs long before it could be painful to a child's fingers.

Each student can be asked to make a chart for recording his observations. Some of the better of these can be reproduced on the chalkboard. You might then take the best ideas and design a final chart. This can be copied by the students and used at home for recording the results of their experiments. It is not important how many times each method is tested. The students should make as many trials as they can.

The lesson which follows the experimenting might be initiated by asking the children which was the best way to make the mealworm back up. Despite the quantitative evidence, there will undoubtedly be no complete agreement. "Perhaps it would be better if we added together everyone's results." One way to tabulate class totals is to list, at separate places on the chalkboard, the different methods tested. The students can then go to the board and write their figures in the appropriate columns. When the columns have been totaled, they can be summarized on a master chart. The final figures will show that some ways are better than others. You might ask the children to rank the methods from best to worst. The results from one class are shown in Chart 2. Touching the antenna with a pinhead was best, but what is next best? Shining a flashlight made the mealworm back up 198 times in 334 tries, and the hot nail worked 247 times out of 330. Clearly this is an ideal example to show the value of computing percentage.

WHAT WAS DONE	TIMES TRIED	TIMES BACKWARD	RANK FROM BEST TO WORST
HOT NAIL	330	247	2
FLASHLIGHT	334	198	3
BLOCKING WITH HAND	242	131	4
TOUCHING ANTENNAE WITH PIN HEAD	268	212	1
MEALWORM AT EDGE OF PAPER	223	19	5

CHART 2. The Best Way to Make a Mealworm Back Up.

Some Additional Work on Backing Up

"Why didn't everyone get the same results?" A variety of possible reasons may be suggested by the class. One answer to this question might come from the realization that there were still differences in the techniques employed, in spite of the precautions to avoid this. Also, students may have noticed differences in the reactions of the same mealworm to a particular stimulus, and differences between different mealworms. Such things as rough or repeated handling, hunger, age, and environmental factors can affect the responses of a mealworm.

The class totals could be compared with those of other groups of children. You can use the results shown here or ones from classes you have taught in the past. Some mention might be made of what the observations on backing up tell about those things which mealworms can detect. "Would mealworms back away from an unlighted flashlight?" "Do you think that mealworms can feel heat?" "Why do you think so?" "When you use a hot nail, do mealworms back up because of the heat, or because they see the nail, or for both reasons?" "Would cool air make a mealworm back up as much as would the warm air from your mouth?" "What other things (like smells, smoke, and wind) can mealworms detect?"

Perhaps interested students could attempt to measure the sensitivity of different parts of a mealworm's body to some of the stimuli. "Can he feel air on his tail as well as on his head?" "How would you find out?" (It is a curious thing that mealworms seem to back up regardless of the wind's direction.) Some other children might want to experiment to see how dim a light can be detected by a mealworm. "How could you find this out?" A bright light could be shined at a mealworm and made a little dimmer on each successive trial. (Dimming can be accomplished by moving the light progressively farther away or by covering it with various thicknesses of cloth or paper.) "What might it mean when the mealworm no longer backs up?" "Would it make any difference if you started with a dim light and made it brighter each time?" In one class some children became interested in the effect of poking mealworms gently with sharp and smooth objects. They found, to their surprise, that more mealworms backed up when touched with smooth things than when touched with sharp ones.

NOTES

7. How do Mealworms "Explore" a Box?

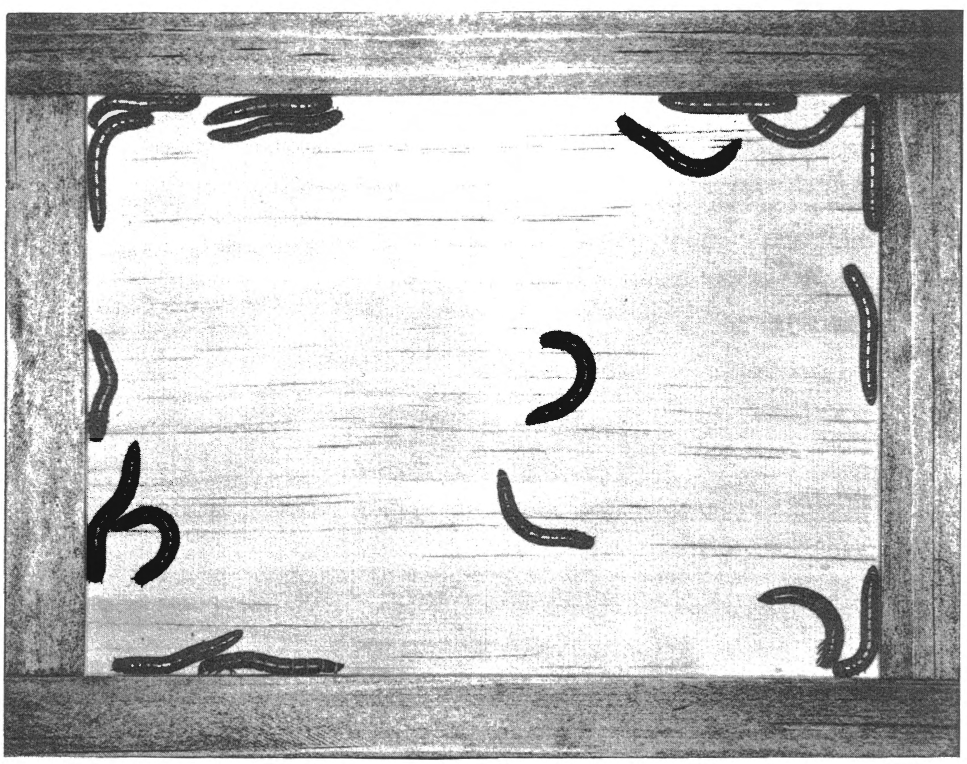
In this exercise, children measure the movements of mealworms which are confined in a box.

Watching Mealworms in a Box

Children should be given suggestions for getting or making a box to use in their experiments. It should be about the size of a shoe box or cigar box. Glass and metal containers are not desirable, because mealworms cannot walk well on smooth surfaces. "How can you keep a mealworm from climbing out of an open box?" A ring of transparent mending tape stuck around the top of the box makes a slippery surface which prevents the mealworms from escaping.

The students are told to put mealworms in their boxes and see what they do. (See Figure 10.) A transition from the previous exercise can be made by asking the question: "Do mealworms ever move backwards in the box for no apparent reason?" When watching for backing up, the pupils will see other behavior as well. After watching the behavior of their mealworms in their boxes at home, your students can report their observations in class.

FIGURE 10. Mealworms Exploring a Wooden Box.



Some things which children have said about mealworms in boxes are:

"They explore in groups.

It likes to climb up the walls of the box.

They are always trying to get out.

They don't start climbing walls until the whole box is explored.

They give up in about 15 minutes.

They usually just sit around when they know they can't get out.

He likes the sides of the box."

Measurement of Exploratory Movements

Following their initial observations, the students will examine more carefully the way a mealworm travels in his "exploration" of the box. Ask questions to direct thinking along this line after allowing the children to say what they want. "Does he spend most of his time following an edge?" "How much is most?" "Where does he climb more, up the sides or up the corners where two sides meet?" "How much of the time does he stand still?"

Disagreements about where a mealworm travels in his exploration of the box will probably arise. If not, difference of opinion can be encouraged through questioning. "Did everyone's mealworm mostly climb up the corners?" "Do all mealworms follow the sides of the box?" "Where do mealworms spend most of their time in the box?"

One way to help resolve some of these problems is to find the time spent by the mealworms in different parts of the box. Students will probably experience difficulty in deciding for themselves that time can be used as a measure to sharpen up their observations. "What can we do to be more accurate?" If the idea of timing cannot be developed through discussion, the children will have to be told.

"What can we use to keep track of the time?" A clock will probably be suggested, but you can mention the difficulty of watching both the clock and the mealworm at the same time. The children could work in pairs, so one could watch the clock and the other the mealworm. "How could we do it so everyone can watch at once?" You will probably have to introduce something yourself. A metronome vibrating at approximately one tick per second is a good time-keeping device because it permits uninterrupted observations. If you can't get a metronome, you might improvise one of the homemade timing devices described in Appendix I, pages 41-43.

The particular types of exploratory behavior to be examined should be chosen as much as possible by the pupils. Suggestions can be written on the chalkboard and discussed. Children usually invent too many categories to observe. To keep it simple, some things might have to be eliminated and others combined to make a single category. Charts developed by two different classes are included here for comparison. (See Charts 3 and 4.) The figures shown are class totals.

CHART 3. Class A.

TIME MOVING	TICKS	TIME STOPPED	TICKS
IN MIDDLE	7,068	IN MIDDLE	5,107
ALONG EDGES	14,802	ALONG EDGES	7,138
IN ANGLES	2,099	IN ANGLES	2,271
ON CORNERS	4,597	ON CORNERS	2,262
ON SIDES	6,254	ON SIDES	2,835

CHART 4. Class B.

ACTIVITY	TOTAL TIME IN SECONDS
STOPPED	929
MOVING ON BOTTOM	4,751
MOVING ALONG EDGES	11,380
CLIMBING UP SIDES	3,435
CLIMBING UP CORNERS	3,670
MOVING IN CORNERS	1,323

Some decisions should be made about the meaning of each category. For example, some clarification of what distinguishes the middle of the box from the edge may be necessary —that is, clarification of at what point the worm is to be considered to be at the edge. It was decided by one class that to be along an edge, a mealworm must be no farther away than the width of one mealworm. Every other place on the bottom of the box was then called the middle.

You can suggest a procedure for tabulating the time spent by the mealworms in the various places. If a mealworm is walking around the middle of a box, the observer should continue to count time until the mealworm begins to follow an edge. When this happens, the time spent is quickly written in the appropriate space on the chart and the counting is begun again. When the observations are completed, figures for each category can be added to make individual totals. These can be entered on a large summary chart on the board so the class totals can be computed. If thirty children count for a half hour, there could be some 50,000 seconds accounted for.

An easier way to measure box exploration is to take a sampling of the mealworm's location at regular intervals. Once every minute, for example, the students can record their mealworms' positions. Equally valid results can probably be obtained if the sampling is done irregularly.

One class period should probably be devoted to timing mealworms in boxes. The children should bring their mealworms and boxes to school for this purpose.

Perhaps as the students study their results they can make more definite statements about exploration. You might ask for a written analysis of the results as a homework assignment. Perhaps your children could express as fractions or percents the relative amounts of time that the mealworms spent still or in motion and in various parts of the box. Since the percents will not come out evenly, some approximating will have to be done.

NOTES

8. How Does a Mealworm Know it is Under Bran?

This question of how a mealworm knows it is under bran provides a chance for new experiments. One difficulty is that there is almost certainly more than one stimulus involved in the mealworm's ability to stay under the bran. (See Appendix III, page 46.) At all events, the question cannot be solved conclusively, because the number of variables is so great that it is impossible to control them sufficiently. This is the most important lesson to be learned from the exercises.

The children can be asked how mealworms know they are under a bran pile once they find it. Some possible explanations for this behavior, as offered by the pupils, might be that mealworms remain in the bran because it affords food, darkness, weight on the back, quietness, or pleasant odor. Of these ideas, the first three are the most suitable for further study and can be treated separately in some detail.

Any other possibilities might be disposed of by a discussion to show why they are probably not the cause. Loud noises have no apparent effect on a mealworm. Even so, how much quieter would it be under the bran? A quick check will show that bran has little or no smell. But does this mean that mealworms cannot smell it?

The questions of weight on the back, darkness, and food can be explored by all the children, by smaller groups within the class, or by interested individuals. Oral reports could be given to describe the experimentation that was carried out. Students can demonstrate in their reports any special equipment which they made to help solve their problem. Appropriate charts should be designed and used for recording data from these experiments.

Do mealworms stay under bran because they eat it? Piles of other materials such as pencil shavings or chalk dust could be put into a box along with bran. Will the mealworms show a preference for bran? Do they behave differently when they are hungry? How can you make mealworms hungry?

Testing for the Effect of Light

Does a mealworm know it is under bran partly because of darkness? How could this be found out? Many ways will probably be suggested and can be carried out. Among the most convincing is to see that mealworms do not collect under the bran nearly as much when the box is dark. Does this show that mealworms go under bran to avoid light? Or is this because they can't see the bran in the dark and are unable to find it?

The question could also be raised of just how dark it is under the bran pile. How could you find out? It might be possible to make a huge mound of bran so children could crawl under. But this is not too practical. How dark is it under a pile of leaves? One way to find out about the darkness under a little pile of bran would be to get a box and cut a small (one-inch) hole in the bottom. A window can be made by covering the hole with a piece of glass or clear plastic, or plastic wrapping taped at the edges. Then a pile of bran can be made over the window. Children can see how dark it is under the bran by looking into the box from underneath or through a peep hole cut in the side. (See Figure 11.) Is it dark inside the box? Suppose a light is placed under this glass-bottomed bran pile; will mealworms still stay under the bran?

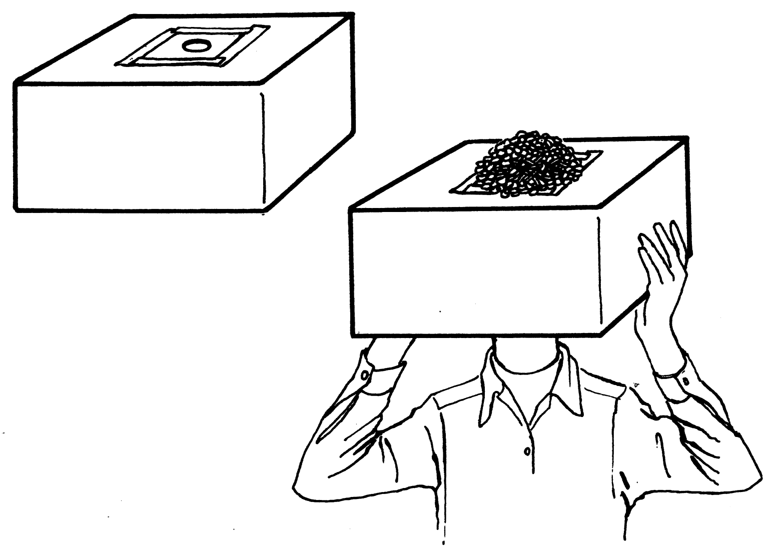


FIGURE 11.
Diagrams of "Window-Box."

Testing for the Effect of Weight

Does the mealworm know it is under bran partly because of the bran's weight on its back? What kind of material must be used to test this idea? See if your children can realize that something is needed under which a mealworm can crawl, but which will not provide darkness or food. Why wouldn't a pile of sawdust or chalk powder be good? How would you know if mealworms stayed under sawdust or chalk because of the weight on their backs or because of the darkness? What could be used for these experiments that would be better? You can have the students offer ideas, and the suggestion of shredded cellophane or similar transparent flakes might be given. A piece of such material could be cut up for experimentation.

Behavior of Mealworms in the Wild

You might want to discuss with the children the significance of what they have learned about the behavior of mealworms in relation to the mealworm's natural life. The children could try to explain how a mealworm's "liking" for dark places might be useful. Suggestions such as hiding from enemies might come up. Could this idea be tested? If a toad, field mouse, circus chameleon, or some other animal which eats mealworms is placed together with buried mealworms and mealworms in the open, which mealworms are eaten most frequently? Perhaps the mealworm's tendency to back away from light and to follow walls enables them to find dark places.

Suppose a predator ate more mealworms in the middle of an empty box than along the edge. This might show that the mealworms were protected by their wall-following behavior. It could be, however, that the predator would "know" where to look and would eat no mealworms out in the open. What might this show?

The survival of a mealworm population depends, perhaps, more on the location of a good supply of food than on the protection from predators. Experiments may have already indicated that wandering and chance "bumping" into food enables the mealworm to locate it. Is the mealworm hatched in a supply of food or does it wander until a supply is located? The adults could be given a variety of egg-laying sites to see where most eggs are laid. If wandering is found to be the means of locating food, does the newly hatched larva wander more?

NOTES

9. Suggestions for Evaluation

In working with mealworms your children, hopefully, will have learned a great deal not only about ways of experimenting but also about the sensory perception of mealworms. It is rather difficult to devise a test to measure what has been accomplished. Several possible means of evaluation are described below. Perhaps you can try some ideas of your own.

Written Tests

A teacher in Vermont used an interesting written test. She described a hypothetical animal called a Snoogle and stated that large numbers of these animals were often found under rotten apples. The children were asked to give four or five reasons to explain this behavior, and to describe some experiments which they could do to indicate which explanations were correct. A few of the answers follow.

> "Some of the possibilities to explain why Snoogles go under apples are:
> 1. They eat apples.
> 2. They might have hatched near apples or on apple trees and are too lazy to move anywhere else.
> 3. They might not like light and stay under the apples or in them to stay away from the light.
> 4. It might be that when the apples fall, other bugs go near them and the Snoogle eats these other bugs.
> 5. It might be that the apples put a special chemical in the ground that can't be found elsewhere."
>
> "To see if they eat the apples, you could try feeding them other types of food. If you found that they do eat the apples it might be that they don't travel very well, and like to stay near their food. A better experiment would be to put them in something with the same texture as rotten apples, like mud. If you find that they can't live in mud, it might be because the Snoogles ate the apples and couldn't eat the mud. If they were just as happy in the mud, you could assume that they didn't eat the apples, but like the feel of it."
>
> "To prove the assumption that Snoogles are allergic to light or warm temperature, the Snoogle could be put in a box, completely dark, with one or two rotten apples in it. If he still went under the apple, it would not be to escape from the light. By having a lighted box but a cool

to cold one, you could tell if he went under to escape the warmer temperature. Then if he went under a rotten apple, it would not be because of a cooler temperature under it."

Before beginning the unit, another teacher had his students criticize some of the hypothetical experiments in Section 5. By doing this again when the mealworm study had been completed, he could compare these criticisms with those made previously.

Students could also write stories about mealworms. If mealworms could talk, how would they describe the experiments that were done on them? What would the "Jolly Green Giant" say about human behavior if he could observe only from a distance what we do?

Comparing Mealworms' Behavior with that of other Animals

One teacher who used *Behavior of Mealworms* with her third grade children had an evaluation exercise with her mealworm class and another similar group of children which had had no contact with the unit. The children went to the junior high school science room and observed animals such as mice or hamsters for about ten minutes. They were asked to describe fully all they had noted about the animals (structure and behavior) and to pose a question which they might be able to answer by experimenting. The teacher reports that, as a group, the class which had worked with the mealworms made better observations and asked more meaningful questions.

Another type of exercise could involve the comparison of the behavior of another kind of insect with that of mealworms. You might be able to find ants, beetles, or other insects outside. Students could each take home a new bug, experiment with it, and write a report of their findings.

Mealworm beetles (grain beetles) could be used if you can get enough of them. Can beetles be made to back up in the same ways that mealworms can? Do beetles follow walls? Can the beetles find a pile of bran quicker than mealworms? Do beetles eat bran? The report below was written by an eighth grader who had studied mealworms two years previously.

"*I tried the experiment concerning itself with which part of an open box it prefers best, on the bottom of the box, near the sides, near the corners, on the sides, or on the corners.*

I began by getting a box, then placing the beetle in the center. Then letting it go and each time marking its resting place. I tried this twenty-five times. As far as perfecting the experiment goes, I made sure the box was on a level surface and that it was equally lighted throughout. Each time I marked his resting place I returned him to the center of the box and started him again. There was never any pattern as to which part of the box he went to, so I think it is reasonable to assume that my conditions were fairly good.

My findings were that out of twenty-five tries, thirteen times it halted on the sides, eight times on the corners, three times on the bottom of the box, one near the sides, and none near the corners. This comes out to 52% of the time it went up the sides, 32% of the time it went up the corners, 12% of the time it remained on the bottom of the box, 4% of the time it came and stayed near the sides, and 0% it came near the corners to stay. This is opposed to the findings that 75% of the time the mealworms made straight for the corners and right up them. This shows a possible change in the climbing methods as the insect changes from mealworm to beetle. This change is also evident in the different type of body structure. Insects like beetles, flies, and ants all seem to have this type of method of climbing on flat surfaces, but, however, the animals such as the mealworms and caterpillars find it easier to climb with the use of cracks and corners where they take full advantage of the two or three climbing surfaces. This change is much like the change from a caterpillar to a butterfly and it emphasized strongly the body structural change in it. ”

Here are a few conclusions from other reports:

“ *From this you can infer that like the mealworms the beetles prefer darkness.*

From these experiments I do not think that mealworm bugs are affected by light. I tried to look for eyes but he wiggled too much.

To conclude, I would say light does affect beetles so they must see or have some other sense that can detect light for them.

Conclusion: The beetle does not have a preference to light or dark, but it has a definite preference to heat and cold. The beetle prefers coolness greatly over heat.

As far as I can tell from this, they have no real preference for hot and cold, the beetles going to the hot end in only one more trial than the cold. However, it is interesting to note that when I took the beetle out of the cold pile of bran he was sluggish and that when I put him near the warm pile he became more active. This worked several times.

This would show that these beetles, at least the ones I had, were not affected by noises, and that they like the sides and corners of box tops. To the best of my memory, mealworms also liked the sides and corners of boxes. They, too, were not bothered by noises. This does not mean that the beetles and mealworms do not hear, though that most likely may be the case.

From my experiments I found the mealworm beetles use their wings, not to fly, but as a parachute when falling or getting over large obstacles. ”

ODE
to a
MEALWORM

by
Lora Fleming
Park School
Brookline, Mass.

Pity the poor mealworm
He is not an ideal
          worm
In fact, he's not a real
          worm,
But a bug,

          Ugh

And when he sought the bran
He couldn't escape my scan
No matter how hard he ran,
     What a bug,

          Ugh

The End

APPENDIX

APPENDIX

I. NOTES ON MATERIALS

There is no kit of materials for *Behavior of Mealworms.* The materials needed are quite ordinary and can be obtained locally. Mealworms can be purchased from one of the sources listed on pages 42-43.

List of Materials

a few pounds of bran or several boxes of dried breakfast cereal flakes
Mealworms are usually kept in bran, which can be bought in farm food stores. Breakfast cereals such as cornflakes, Wheaties, and 40% Bran Flakes seem to be just as good as bran. Large flakes like these should probably be crushed into smaller pieces.

large can or jar to keep the mealworms in
Such a container should be wide enough to reach into easily. The jar or can should be covered to keep the bran dark and moist.

50 waxed-paper sandwich bags
Children can carry their mealworms home in waxed-paper bags. An improvised envelope, made by folding and stapling a piece of paper, could be substituted for a waxed-paper bag.

magnifying glasses or microscopes
A medium-powered *binocular* microscope is ideal for looking at mealworms, but one may be difficult to obtain. A simple hand lens works well.

photographs of mealworms
A set of 6 enlarged illustrations of mealworms is available for use with this unit. To obtain these write directly to the **Science Product Manager, Webster Division, McGraw-Hill Book Company, Manchester Road, Manchester, Missouri, 63011.**

metronome or homemade time keeper
Although a metronome is probably more convenient, you might make your own timekeeping device. To make a water dropper, punch a hole with a needle in the bottom of a gallon or half-gallon plastic bottle. (The hole can be enlarged if a faster drip rate is desired.) Suspend this over a pie plate which is inverted in a bucket. When water is put into the bottle, drops will fall at regular intervals and make audible taps as they strike the pie plate. The top of the bottle should be left off. (See Figure 12.)

Another way to keep track of time is with a large pendulum. A heavy object can be suspended on a string and swung back and forth. One child can tap with a stick in rhythm with the pendulum. Tapping out time while watching the second hand of a watch or clock would also work. Perhaps your children can invent some other ways of keeping time.

materials for constructing walls
Some or all of the following materials and tools might be used for wall building: strips of wood and plastic, cardboard, heavy construction paper, aluminum foil, transparent plastic wrapping, masking tape, transparent mending tape, wire, knives, scissors, coping saw, and pliers.

other common supplies
Other supplies that might be required (depending upon the activities the children decide to do) are: straws, rulers, chalk dust, sawdust, cellophane, match boxes, flashlights, and shoe boxes. In the event that such ordinary supplies are needed, you or your children can probably get them without too much difficulty.

You might wish to duplicate papers with some descriptions of hypothetical experiments which are used in Section 5 (see page 20) and the charts for recording the tracks of mealworms, described in Section 4 (see page 16).

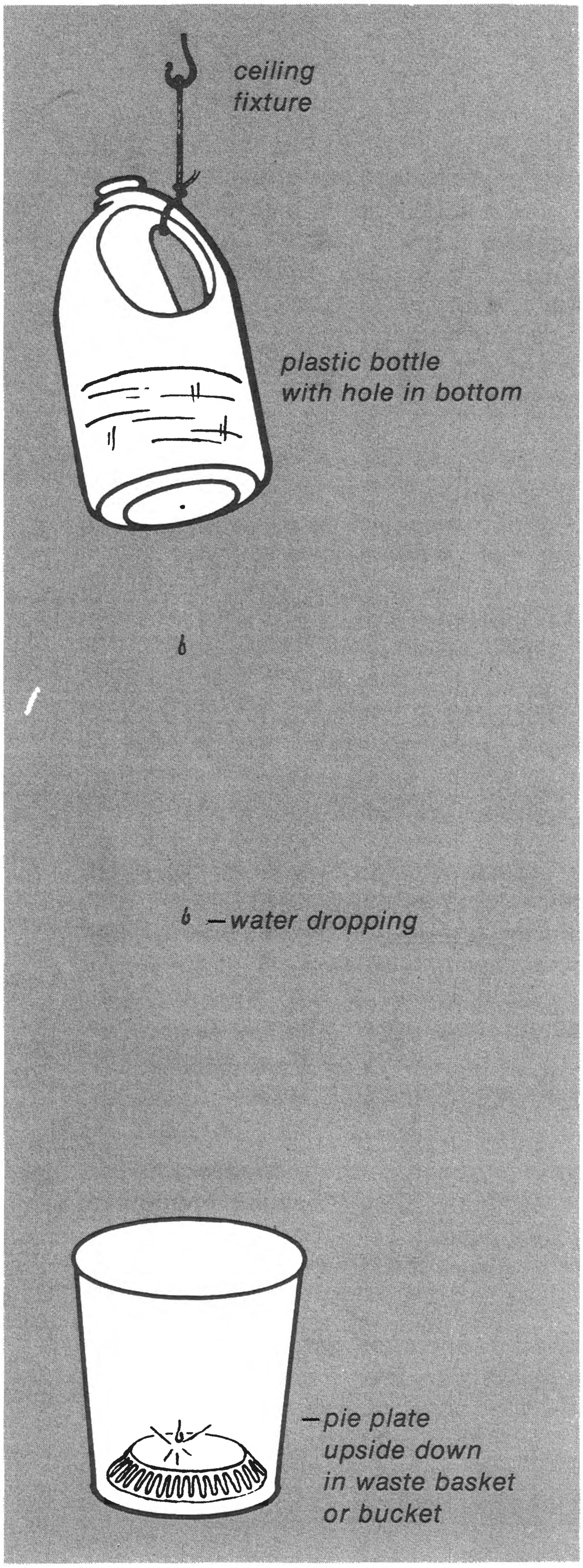


FIGURE 12. Diagram of Water Dropper.

How to Obtain Mealworms

To teach this unit, you should have mealworms available in sufficient quantity to replace those which die, get lost, become listless, or develop into beetles. Several mealworms should be kept by each pupil for use at home. The remainder can be kept at school for experiments which take place in the classroom. Six hundred should be plenty for a class of 30. After being kept for three or four weeks, mealworms may become less active. In order to have responsive mealworms for the later experiments, 300 mealworms can be ordered for the start of the unit and another 300 after several weeks.

Local pet shops often sell mealworms, and they can also be purchased at biological supply houses such as:

Dix Dock
P. O. 427
West Palm Beach, Florida 33402

Mrs. Eleanor Sylvestor
Brockton Worm Hatchery
18a Fuller Street
Brockton, Massachusetts

Carolina Biological Supply
Burlington, North Carolina

Macalaster Scientific Corporation
60 Arsenal Street
Watertown, Massachusetts

Turtox Biological Supply House
8200 South Hayne Avenue
Chicago 20, Illinois

Each month, mealworm suppliers ship thousands of mealworms to university biology laboratories, hospitals, and pet shops. Mealworms are used to feed such animals as bats, monkeys, chameleons, toads, lizards, fish, salamanders, and praying mantes. Mealworms have been widely used by insect physiologists to study respiration, digestion, excretion, and other body functions of insects.

II. INFORMATION ON MEALWORMS

Care of Mealworms

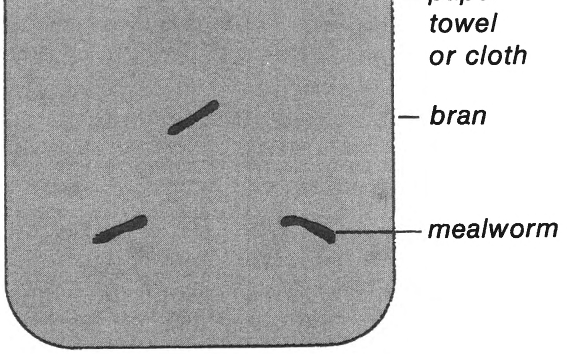
For studies of behavior to be successful, you must have active mealworms. Even when given the best of care, mealworms sometimes become listless after two or three weeks. When this occurs, fresh mealworms must be obtained before the study proceeds.

Mealworms are usually shipped in crumpled newspaper inside a paper cup. When your mealworms arrive, open up the paper over a table or desk. Shake or scrape the paper so that all mealworms fall off. Then push them into a pile and off the edge of the desk into a glass or metal container. Students can keep their few mealworms at home in a small jar with a little bran or breakfast cereal flakes. (See Figure 13.) Cardboard boxes are not suitable, since mealworms can climb out or chew their way through the bottom.

The noise that mealworms make in a container of bran is an indication of the great activity which sometimes occurs.

Four or five handfuls of bran or cereal flakes will support 500 mealworms for many weeks. Fresh bran should be added when most of the old bran becomes reduced to powdery size. Very little water is needed by mealworms, since they have the ability to extract water from carbohydrates in their food. In spite of this fact, however, mealworms do seem to be attracted to moisture. Thus, it might be advisable to make water available by occasionally giving mealworms some moist food, such as a small piece of potato, apple, banana, lettuce, or celery. A wet paper towel or a piece of cellulose sponge can also be used. If the bran becomes too wet, it will

FIGURE 13. How to Keep Mealworms.



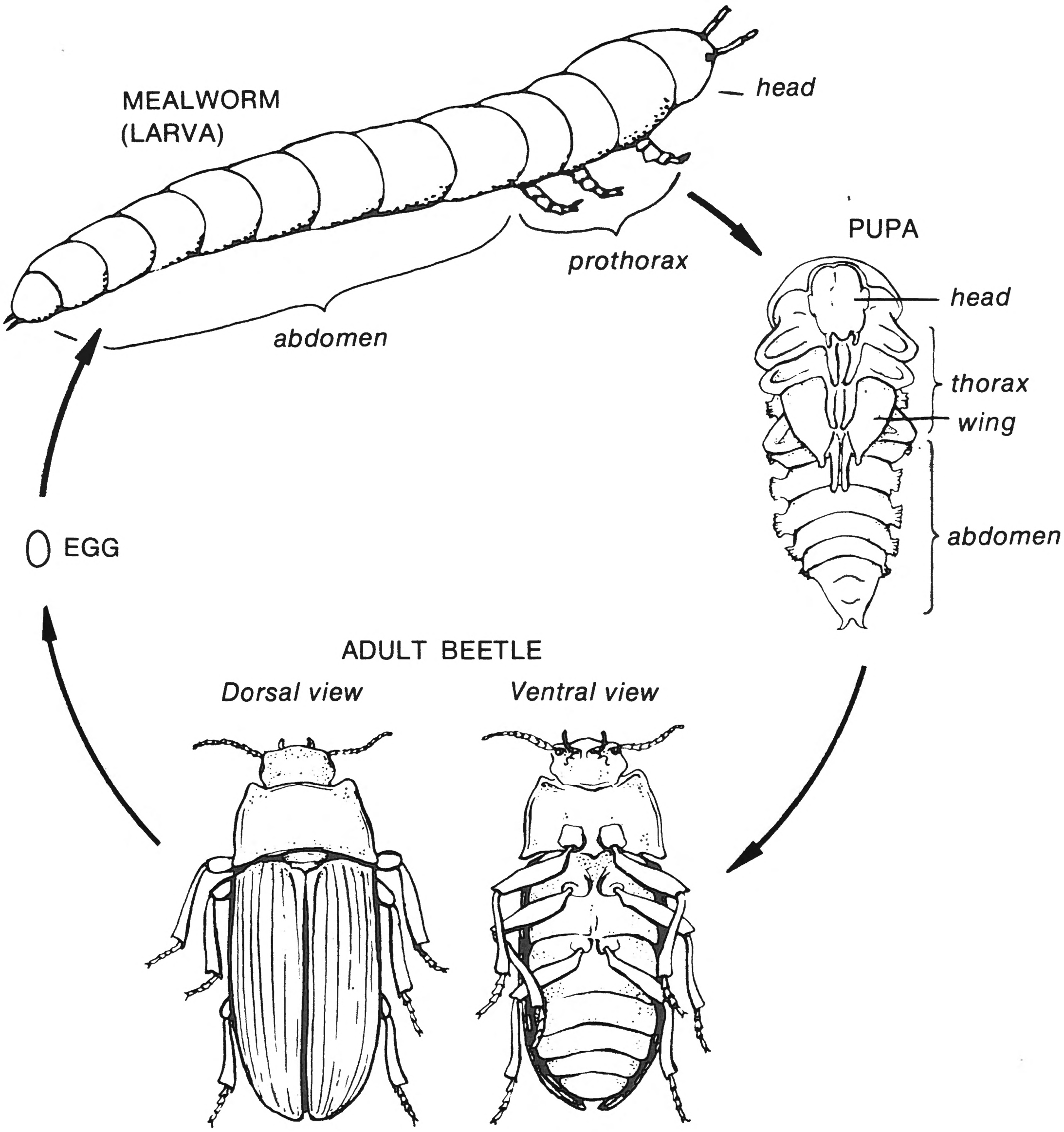
become moldy and the mealworms will not grow well.

Mealworms eventually change into pupae and finally beetles. (See Life Cycle of Mealworm, Figure 14, below.)

The beetles must have a good supply of moisture in order to live and lay eggs. After their eggs have been deposited, the beetles die on top of the bran and should be removed. In order for the eggs to hatch, the bran should be left undisturbed for several weeks.

It is not too difficult to maintain a mealworm culture from one year to the next. If provided with a constant supply of cereal flakes and some moisture, a mealworm population will continue to reproduce itself. During the summer months, a responsible child could care for the mealworms at home.

FIGURE 14. Life Cycle of Mealworm.



Four Stages of Growth of ***Tenebrio molitor*** (4x)

Life History of Mealworms

Mealworms are the larvae of grain beetles, *Tenebrio molitor*. This beetle, like many other insects, has four distinct stages in its life cycle: egg, larva, pupa, and adult. (See Figure 14.) Such a pattern of development is known as complete metamorphosis. This is in contrast to the growth of insects, such as grasshoppers, where the young are identical to the mature adult.

The tiny eggs are white, oval shaped, and about one-twentieth of an inch long. They are covered with a sticky secretion that causes them to become quickly coated with particles of food stuff. Under favorable conditions the eggs hatch in about a week.

The thread-like larvae (mealworms) which emerge begin to consume food immediately. As the larvae grow, they become too big for their hard skin. Mealworms shed their skin from nine to twenty times, allowing them to grow larger. When fully grown, they are about one inch long and one-eighth inch in diameter. Their color is yellow, shading to yellowish-brown at each end and where the segments join. The larval stage continues for about four or five months, depending upon the temperature, moisture, and food supply.

Fully developed mealworms change into inactive pupae, which at first are whitish in color, and then slowly darken. The pupae are somewhat shorter and fatter than fully grown mealworms. The segments across the back resemble an accordion. When prodded, the normally still pupa flips these hind segments back and forth. The pupal stage lasts one to three weeks.

When the adult beetles emerge from the pupae, they are completely white, but they gradually turn brown and finally black. The beetles' wings are vestigial, as they are not used in flight. An occasional hop of from three to five inches seems to be their limit. You could ask the children to find out if the beetles can fly. The beetles, often known as darkling beetles, usually live only a few months. Male and female beetles cannot be distinguished from one another. Female beetles may lay up to 500 eggs before they die.

Interested students might wish to do some elementary research on the environmental factors which affect the rate of development of the mealworm.

"*First, we tried an experiment to see how light affects mealworms. Light really doesn't matter, but we found out that warmth affected them. First, we kept some mealworms in boxes on our desks where it is quite cold. We put some more in a jar in the window over a heater. In two days the mealworms in the jar had changed into the pupa stage. After two weeks, the mealworms in the box still hadn't changed. This experiment shows, that if mealworms don't have warmth, they won't change into beetles. They will just die as mealworms.*"

Natural Habitats of Mealworms

Mealworms usually live in dark, damp places, such as in accumulations of grain in neglected corners of mills, under bags of feed in warehouses and feed stores, or in the litter of chicken houses. Mealworms are primarily scavengers and prefer to feed on decaying grain or milled cereals that are damp and in poor condition. However, they will devour meal, flour, bran, grain, coarse cereals, bread, crackers, mill sweepings, meat scraps, feathers, the bodies of dead insects, and similar materials.

When fully grown, mealworms wander about, probably in search of a place to pupate. Large numbers frequently collect in strange places and cause more trouble by their mere presence than by the actual damage they do in feeding. They have been found in bags of fertilizer and of salt, boxes of soda ash, bales of tobacco, and ground black pepper.

Where did mealworms live before there were grain mills and feed stores? This seems to be a difficult question. Several university entomologists were asked if they know the answer. They did not, so they consulted books on the ecology of grain beetles. The only information they could find related to mealworm infestation of grain stored by man.

It seems likely that mealworms at one time inhabited environs other than man-made grain piles. Probably some still do. Perhaps they can subsist on a diet of dead leaves or rotten wood. Could they survive on the scattered seeds of dead grass knocked down by snow in the winter? This seems improbable, since there would presumably be long periods when there were too few seed supplies. Maybe they lived in the grain caches that some rodents make.

III. ON EXPERIMENTING WITH ANIMALS

Some precautions on using this section of the appendix are in order. The ideas developed are too involved to be taught as "Directions" or "Instructions" for experimentation. What is offered is rather a discussion of complexities that will, and should, be allowed to unfold gradually as the pupils experiment with mealworms.

The danger is that students may become discouraged if all the qualifications for experimentation mentioned here are heaped on them too soon. They should first go their own ways for a while and develop some feel for mealworms and for experimentation. A student who has found that mealworms back away from a match has learned something important, whether he knows what aspects of the match caused the retreat or whether he even knows that there might be something other than heat involved. An education in science must have simple beginnings, much as every problem in science must have a simple beginning. As one's science education progresses, he gets closer and closer to a knowledge of what he must bear in mind while experimenting. But no one alive can say exactly what it is necessary to know in order to do research—one's education never stops. Science, too, is continuous; it has no end; no ultimate truth is reached. At best, what is achieved is a better and better approximation of an unattainable truth.

It is not true that progress in science is invariably achieved by employing the "Scientific Method." Probably few scientists make real progress by adhering to the scientific method or, for that matter, to any set method. As a useful tool the scientific method can be best employed only when one has the clear advantage of hindsight; it is of little help when one needs foresight.

Though the scientific method is by and large unused during creative moments, it *is* later employed for reporting the research, and it *is* the context in which the reader learns what has happened. For when a paper is presented, so neatly does each step lead to the next that one may be left with the impression of a scientist as a man who thinks on a plane of complexity no layman can ever share. What rarely, if ever, reaches the reader are: first, the elements of luck, frustration, and hunch playing that are involved in research; and second (and perhaps more important), the fact that almost without exception important contributions to science are not incredibly complex ideas but beguilingly simple ones arrived at by beguilingly simple paths of reasoning. The complexity lies not in the reasoning process, which is simple at any level, but in the accumulated experience with which one approaches a problem.

In making these disparaging remarks about the scientific method, we certainly do not wish to imply that it has no value. The rigor it imposes has been uniquely responsible for the evolution of science into the powerful discipline that it has in fact become. The scientific method is essential to science, but in teaching only that to students one is teaching them about the *history* of science and not about the way that scientists think. When a scientist finds occasion to concern himself with the scientific method, he is being the critic, not the creator of an idea—whether that idea is his own or someone else's.

Children should not be taught that science can be carried forward only by selected people with extremely clever wits. They should begin to realize that the sorts of experiments they themselves devise, if carefully done, are often just as good as those performed by other people called scientists. It should not be thought, however, that there is nothing worth learning about how to approach problems. On the contrary, one of the things students should gain from an education in science, besides a background of information, is an appreciation of the fact that certain approaches are likely to be more fruitful than others. This section of the appendix is included with *Behavior of Mealworms* in hopes of providing some of the experience that will help teachers and students in designing fruitful experiments and in interpreting them.

Variable Results

Certainly a problem one will encounter when studying the behavior of mealworms is the variability of results. The pupils may have difficulty in seeing enough uniformity in the mealworms' responses to enable them to draw unequivocal conclusions. Some discovery of this inability to know for sure is valuable, as is firsthand experience with the frustration of inconclusive results.

Some of the causes of variability in mealworm behavior result from changes in the general physiology of the mealworm. These are changes that occur within the mealworm, such as growth, aging, approaching pupation, fatigue, adaptation, and being well-fed or hungry. In some insects, it has been shown that succeeding stages in their life bring out highly variable and sometimes directly opposite responses to external stimuli. While one certainly will not aim to know the exact physiological state of every mealworm in class, an awareness that such factors influence behavior can help. It can show the necessity of repeating experiments more than once, on different days, with different larvae, and of drawing conclusions only from a large number of samples and trials.

Environmental factors, such as temperature, humidity, chemicals, and light also affect mealworms' behavior. Although these cannot be kept constant in a classroom, the teacher might want to encourage children to pay attention to sudden changes in temperature, humidity, light, and so on.

Sometimes variations in mealworm behavior cannot be readily explained by physiological or environmental factors. A student should not be made to feel that he is wrong if his results differ from those which others have obtained. Quite the contrary. When doing research, one learns to treasure his exceptions. For only by discovery of that which is an exception to the general rule does one go on to discover the next general rule.

Biologists often complain about the inconsistency of animal behavior. It makes their task of explaining behavior much more difficult. But certainly one fascinating capacity of a living organism is its ability to behave in a variety of ways. By working with mealworms, students may become aware of this.

Controlling Variables and Running "Controls"

The student who has failed to get conclusive results from an experiment is probably making it too complicated: he has not limited himself to a situation where only one thing is being tested. He has forgotten that, just because he is concentrating *his* attention on one part of an experimental situation, the mealworm may be concentrating *its* attention on some quite different aspect.

For example, we want to test whether a mealworm backs away from heat, so we use a match as a heat source and find that the mealworm backs up quickly. We conclude that the mealworm is responding to the heat. Yet we forgot that the match also gives off light and that light also might cause mealworms to retreat. Suppose we prevented the mealworm from seeing the light by putting blinders on it and found out that it still backed up. Still we are not safe in assuming that heat was the stimulus, since the mealworm might have smelled the match as it burned. Even if we could dispense with this, there are other possible things about matches that might cause a mealworm to retreat. Matches make a sound when burning. A match also produces a diminutive, horizontal breeze as the hot air rising above it drags in cooler air from all sides. Matches also are objects with a shape, and perhaps mealworms retreat from shapes which are long and narrow. Thus we confidently used a match to begin with because it is a good heat source, forgetting that at the same time it produces light, smell, sound, and wind, and that it has a shape.

In order to decide just what stimulus or stimuli produced by matches the mealworm *is* backing away from, we might employ either of two standard tricks: 1) We could control all the variables. If we think that heat is important, we make a heat source that is dark, odorless, silent, breezeless, and not visible to the mealworm. Doing this is quite difficult. We might have to bury a wire, heated by electricity, in a floor that would not start putting out odors when heated. 2) To avoid such troublesome equipment building, we might take the second alternative: use a series of control subjects (often called "controls" for short). In this case, instead of removing *all* the stimuli *except* the one we are interested in, we remove *only* the stimulus we are interested in. Then we can see whether without it, all the others can produce the reaction we noted when it was present.

The salient differences between these two methods of experimentation are diagrammed below. In both cases letters represent stimuli put out by an object whose effect on a mealworm we wish to test (x is the variable that interests us most). Boxing a variable indicates that it has been dispensed with.

Controlling variables

[a] [b] [c] [d] [e] x

Running "controls"

a b c d e [x]

It should be obvious that when one runs a control, he really does not need to know what other stimuli are available to the animal; all he has to be sure of is that he has removed that stimulus (and only that stimulus) that interests him. For this reason the more common way in which controls are used is in making sure that all unpredictable variables, as well as predictable ones, have been removed. Thus, "controls" are routinely run, regardless of whether variables are controlled.

Animals As Opportunists

Let us suppose that a student has been studying the problem of why mealworms stay under a pile of bran. He performs a good experiment in which he discovers that mealworms prefer dark places to lighted ones. He also finds out that it is dark under any bran pile beneath which mealworms collect. So he decides that mealworms stay under bran piles because such places are dark. But such reasoning is based on an assumption that is almost certainly wrong; i.e. that there is just one stimulus keeping mealworms under bran piles—darkness. Actually, it is probably the sum total of a great many different stimuli that keeps the mealworm beneath the pile. Furthermore a stimulus in isolation probably has a different effect on the mealworm than when it is combined with other stimuli. One fundamental characteristic of animals is that they are opportunists and will usually use whatever information is available to them in order to keep in contact with their environment. If one tries to claim that any *one* stimulus is solely responsible for directing an animal, he is almost certain to be wrong. This kind of reasoning would lead one to say that the fact that a ship which gets back into port after losing its compass in midocean constitutes proof that ships are not navigated by compass. We know that if the usual method for navigation is lacking, some alternative means can be employed.

Cannot vs. Need Not

One of the reasons students fail to realize that animals are opportunists is that they do not realize the difference between an experiment proving that an animal *cannot* use a particular stimulus to accomplish something, and an experiment proving only that the animal *need not* use the stimulus to accomplish it.

The following example is taken from research done by Dr. Roger Payne: I released live mice on the leaf-strewn floor of a room. An owl living in the room could catch the mice even in total darkness. Since the mice made noise in moving through the leaves on the floor, I assumed that the owl was locating them by the sounds they made. However, mice are smelly animals, and maybe the owl was locating them by using its sense of smell. To decide this question, I dragged a wad of paper through the leaves on the floor in the dark. The owl caught the wad. Since the wad had no mouselike smell, the owl could not have been using the sense of smell to locate it. The obvious conclusion is that owls cannot use the sense of smell to locate an object. But that is dead wrong. All I have proven is that they *need not* use smell to locate the wad. That does not mean they *cannot* use smell. "Cannot" experiments are a lot harder to design than "need not" experiments.

It looks as though we can get around the difficulty in this case. I bury a freshly killed mouse in the leaves so the owl does not see it. The owl can be in the presence of such a hidden mouse for an hour or more and never attempt to strike it, even though the mouse is giving off its characteristic odor all the time. However, with the first mouse-like sound that I play through a loudspeaker (the speaker lies under the mouse), the owl strikes the mouse. Aha! I have proven that the owl *cannot* use the sense of smell to locate the mouse, since the owl had to have a sound before it struck. But I have proven no such thing.

It is very common to find that animals need one stimulus before they will use other stimuli, even though the others are present all the time. For instance, a water beetle will pay no attention to its prey, even though it can see it perfectly clearly, unless it also gets the prey's scent through the water. Then it hunts that prey, not by scent, but by eye! This is shown by lowering a test tube containing water and some worms into an aquarium occupied by a water beetle. The beetle pays no attention. But when a bit of worm extract is slipped into the tank at any point, the beetle tries to attack the worms through the walls of the tube. Since the beetle cannot smell the worms through the tube walls it can only be basing its attack on vision. The important thing is that the attack had to be triggered by the smell of the worms.

Back to the owls. One could argue from the experiment in which the owl waits a long time to hear a sound before striking a mouse hidden in leaves, that *sound* had the effect of triggering the owl to locate the mouse by smell. Consequently that experiment proved nothing. I next try putting a mouse under the leaves in one place and a loudspeaker under the leaves in another. The owl will not strike the mouse until I finally turn on the sound. Then it strikes the loudspeaker and ignores the mouse. At last I might think I have proven that the owl cannot use smell. But in fact I have not since it is still possible (though perhaps not very likely) that maybe the owl simply prefers to hunt by sound and goes after the source of the noises even though it knows perfectly well that a mouse was in another place.

However, it looks as though we can say one more thing on the basis of this last experiment. Although we have *not* proven that the owl *cannot* use the sense of smell to locate a mouse, we *have* shown that the owl *does not* use the sense of smell. But, unfortunately, even that is not true. It is the rule rather than the exception that there is a hierarchy among stimuli used by animals to do any particular thing. This probably is true for owls. Though I have never tried it, I will bet, for instance, that a barn owl will catch a mouse that it can see in preference to one that it can only hear. This certainly does not mean that barn owls cannot locate mice on the basis of hearing. I will also bet that a barn owl will use both vision and hearing together whenever it can. It might be that a barn owl uses its sense of smell to help it along in capturing a mouse which it has also located by sound. It would be almost impossible to prove that such was not the case.

Therefore, I am back where I started. I can say only that a barn owl *need not* use the sense of smell, but I am unable to say that it *cannot* or even that it *does not* use it to locate mice. I have succeeded in casting doubt on any theory claiming that owls are able to use smell to locate mice, but I am unable to decide it completely. I might add, parenthetically, that I do believe owls *cannot* use smell to locate mice since 1) they consistently ignore mice they can only smell; 2) their olfactory organs are very poorly developed; and 3) homing on smells is a very sophisticated task and quite inaccurate at best. But this is really only educated guessing on my part.

Orthokinesis and Klinokinesis

In the experiments to see if mealworms can find a pile of bran, students will probably trace paths that are highly tortuous. One is tempted to assume that such paths are random, since they twist and turn with no particular orientation. This randomness may be only apparent, however. To be content with saying that the mealworms simply wander until they collide with a favorable situation would disguise the rather fascinating mechanisms involved. There are two methods which enable lower animals to find favorable locations, both of which result in paths that appear random. These two means of aggregating in favorable localities are called *orthokinesis* and *klinokinesis.*

In orthokinesis the speed with which the animal moves is proportional to the intensity of the unfavorable stimulus to which it is exposed. Thus, an animal which is found most often in moist places will wander around rapidly when placed in a dry locality. If by chance it arrives in a moister, more favorable area, its pace slows (it may stop completely), thus assuring that it spends much more time in the favorable locale.

In klinokinesis the speed of travel is unaffected by favorable or unfavorable stimuli. Rather, only the rate at which an animal turns is affected—the rate of turning is proportional to the intensity of unfavorable stimuli. The turns bear no fixed relation to the direction from which the stimulus emanates; i.e. they are random in direction. To see how this works, let us imagine an animal usually found in dark places. If we put it in a dark place, it will wander about, turning every so often and covering quite a bit of ground between turns. We now switch on a bright light. The animal turns much more often, moving around in a smaller area which it crosses and recrosses.

We can see how this might help the animal in nature by imagining what might be a common location for it—a dappled shade with patches of sunlight and deep shadows cast by rocks, leaves, logs, and so on. Suppose the animal is in a nice dark place and comes to a border between light and dark. Before it hit the border it was turning rarely, but as soon as it goes into the light it turns quickly. Its chances of finding the shade (which is preferred) are great; for even should the first turn fail to restore the animal to shade, subsequent turns will be made before it has gotten very far from the shade, and its chances of blundering back into the darkness are enhanced.

Suppose instead that we place the animal in a brightly lighted space far from the nearest shade. If it continues to make turns in quick succession, it will remain in a limited area and may fail to reach the shade before it gets too much sun and dies. This will not occur, however, because of a universal attribute of animals called *adaptation.* Adaptation means that an animal's response (in this case, turns per minute) diminishes even though the stimulus strength remains unchanged. Thus, what we would observe with our animal in the bright light is that though it makes turns in quick succession when it is first introduced to the light, the time between turns eventually increases until it makes longer and longer straight-line excursions before turning. As it covers more ground between turns, the chances of its reaching new territory, some of which may be favorable to it, increases.

In a case where there is a gradient of light (where intensity of illumination increases or decreases steadily over some set distance) an animal, though apparently wandering at random, is actually skewed toward darker regions. This is because it will tend to make longer trips between turns when moving into darker areas than it makes when the areas into which it is moving are getting increasingly brighter. There is a detailed and highly readable description of this in *The Orientation of Animals* by Fraenkel and Gunn. (See Suggested Reading on page 52.)

Adaptation

Some mention of adaptation has been made in the above example. It should be borne in mind at all times, however, that any animal that is run through a series of tests following rapidly one upon the other will probably be responding differently at the end of the series than at the beginning. This is simply because its sense organs are adapting to the stimuli involved. One should not confuse adaptation with fatigue. If I am running for my life from a brush fire and begin to run slower, it does not imply that my sense organs are adapting and reporting to me that the fire has become less hot and therefore I can reduce speed. It simply means that my muscles are getting fatigued.

Examples of adaptation in humans are common. Surely, everyone has left a pleasant room in which many people are gathered for a party, only to return a few moments later and discover that the room smells like a wolf den. What has happened is that as the stuffy air built up slowly in the room, the smell receptors adapted fast enough so that nothing was reported to the brain regarding bad odors. While people are away from the smells, however, their sense cells are no longer adapted. On reentering the room, the cells do not adapt fast enough to avoid reporting an odor to the brain, and so the odor is suddenly perceived. The odor could not be detected while the sense cells were in an adapted state. Now, even though the odor is no more intense, it cannot be ignored.

The possibility of adaptation must be remembered when experimenting with animals, since an animal whose receptors are adapted will of course require a more intense stimulus before its effect can be detected at all.

Suggested Reading

The books listed below contain further information on animal behavior. You might be interested in reading some of them and in making them available to your students.

Burnett, A. and Eisner, T., *Animal Adaptation.* Holt, Rinehart, and Winston, New York, 1960.

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IV. SOME EXPERIMENTAL WORK DONE WITH MEALWORMS

Scientists have studied mealworm behavior in much the same way as children do in *Behavior of Mealworms.* Although there has been a lot of research on mealworms, only a few investigations are summarized here.

Several papers have been selected to show how experimenters have attempted to control their variables in order to obtain more significant results. One study on mealworm wall-following is similar to some work done in *Behavior of Mealworms.* Another researcher measured the growth of mealworms fed on various sugars. Who would suspect that anyone would ever concern himself with feeding mealworms 25 different kinds of sugar?

Consequences of Artificially Selecting Mealworms for Weight

In a study by Leclercq,[1] mealworms were artificially selected for weight for twelve consecutive generations. This was done by splitting the initial population of mealworms into two groups, one heavy and the other light. In each generation all pupae in the light group weighing more than 160 mg were removed, and all pupae in the heavy group weighing less than 160 mg were removed. This selective process took some eight years. For the next ten years practically no mealworms in the light group were overweight, and only a few in the heavy group were underweight.

During the breeding it became obvious that by selecting for weights, one had also selected automatically in favor of shorter or longer duration of larval development. There were other differences also. The heavy strain produced larvae, pupae, and adults of bigger size and heavier weight. The light-strain mealworms reached the pupal stage more rapidly. Very young light-strain mealworms were more affected by cold. Light-strain mealworms grew better when supplied with food enriched with yeast or when each mealworm was reared individually with special flour. The same mealworms, however, were less affected when fed with cereal flours of poor quality or with artificial diets. Adults of the light strain were much less prolific and laid proportionally fewer fertile eggs. No structural differences between the two strains were detected.

What environmental factors found in a mealworm's native habitat could cause natural selection for weight?

Reactions of Mealworms Crawling along Walls

Observations made by Crozier[2] in 1924 showed that when a mealworm came to the end of a glass plate it was following, it turned in the direction of the plate. (See Figure 15.)

In other tests, mealworms were put between two glass plates arranged to touch both sides of the mealworm. After emerging from glass plates giving equal bodily contact, mealworms followed a perfectly straight course. (See Figure 16.) When crawling along a glass rod, the mealworm raised its head and swung the front end of its body over the source of contact.

If the front end of a mealworm was momentarily touched at one side with a glass rod, the head bent toward the glass rod after it was removed. This response was quickly followed by a return to the original direction. (See Figure 17.)

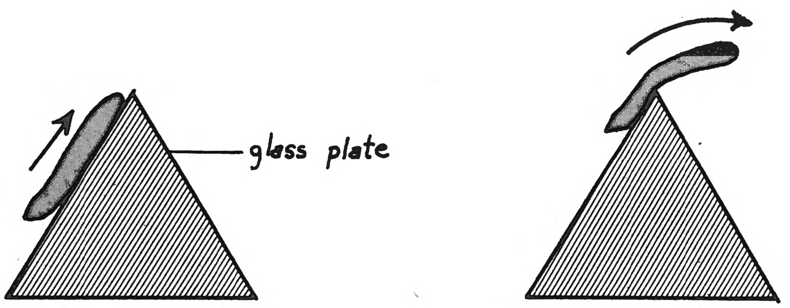
Crozier attributed the tactile sense of the mealworm to the "hairs" which occur along the body. The responses from touching were inhibited by light of sufficient intensity. For this reason Crozier conducted all his experiments in a dark room, under red light of low intensity.

In some situations, mealworms turned away from tactile stimulation instead of toward it as they usually did. For instance, when a mealworm was moving rapidly as a result of previous handling or repeated me-

1. Leclercq, J., 1963. "Artificial selection for weight and its consequences in *Tenebrio molitor.*" *Nature,* 198:106–107.

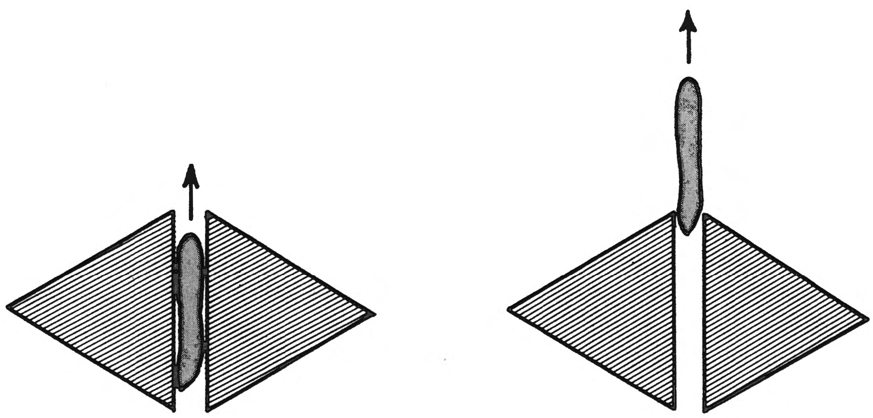
2. Crozier, W. J., 1924. "Stereotropism in *Tenebrio* larvae." *Journal of General Physiology,* 6:531–539.

FIGURE 15.



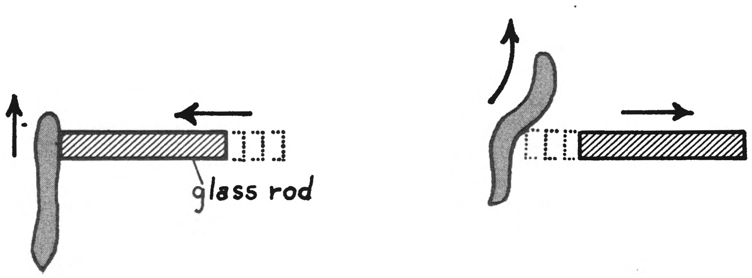
Reaction of Mealworm When Coming to the End of a Wall.

FIGURE 16.



Reaction of Mealworm When Emerging from Walls Touching Each Side of Body.

FIGURE 17.



Reaction of Mealworm When Touched on One Side.

chanical stimulation, it turned away from the edge of the glass plate. Temperatures below 14°C and starvation for several days are also conditions which tended to cause a reverse reaction.

Responses of Mealworm Beetles to Differences in Humidity

In order to investigate the humidity behavior of the mealworm beetle, Pielou and Gunn[3] used a chamber which could be regulated to make the humidity higher on one side than on the other. The chamber was simply a piece of tubing with a moist piece of paper at one end. By varying the length of the tubing and the amount of moisture in the paper, the investigators could offer the beetles a variety of humidity alternatives.

For each experiment, five beetles were placed in a chamber for ten hours. At the end of each fifteen minute interval, the numbers of beetles on both the dried and moist sides of the chamber were recorded. After each recording, the beetles were pushed around the cage to a new position.

Similar experiments were carried out using a control chamber which had a uniform humidity throughout. This was done in order to make sure that no other factors would cause the beetles to gather on one side. Any congregating in the humidity chambers, then, would be due to humidity differences.

Other experimental work has shown that in some insects the direction of the reaction to humidity depends on whether or not the insects have been living in dry air. This variable was eliminated in these experiments by maintaining the beetles in a moist atmosphere prior to the tests.

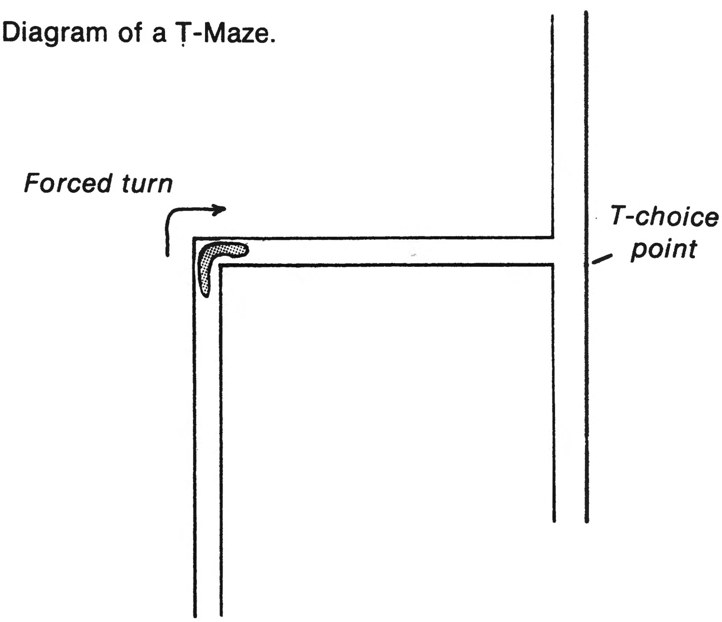
In nearly all the humidity experiments most beetles collected on the drier side of the chamber, regardless of the choice of humidities available. In no case was there a significant excess on the moister side. The intensity of the reaction was determined by the degree of humidity at the moister side of the chamber. The amount of difference in humidity between the two sides was not important in determining the intensity of reaction.

3. Pielou, D. P. and Gunn, D. L., 1940. "The humidity behavior of the mealworm beetle, *Tenebrio molitor*: I. The reaction to differences of humidity." *Journal of Experimental Biology*, 17:286–294.

Reactions of Mealworms in a T-Maze after Making a Forced Turn

A T-maze, as its name implies, is shaped like a "T." If a mealworm is following the stem of the maze up to the cross-bar, it comes to a point where it must choose whether to go left or right. This is known as the T-choice point. A number of studies have shown that for mealworms, the chance of a

FIGURE 18. Diagram of a T-Maze.



turn in a particular direction at a T-choice point depends on the direction from which they turn into the stem of the T-maze. They tend to turn in the opposite direction from the initial or forced turn. (See Figure 18.) If a mealworm turned to the right at the first turn, it usually went left at the T-choice point.

One suggested explanation for this is the so-called "centrifugal swing." According to this hypothesis, the mealworm is carried to the outside wall of the alleyway after the first turn. Then it guides itself along that side until it reaches the T-choice point. Then it will turn toward the side being touched, in an apparent effort to maintain contact. The probability of an opposite turn would decrease as the distance from the forced turn to the T-choice point increases.

In a study by Grosslight and Harrison[4] an attempt was made to minimize the effect of the centrifugal swing in order to see if the mealworm would still turn in the opposite direction. Narrow alleyways were used so that a mealworm would have continual contact with both sides of its body.

When the maze was used, it was placed on a table that was leveled to insure against any biasing effect of gravity in determining turns. In order to have a uniform light over the maze, a 150-watt floodlight was suspended directly over it. To insure further against light-bias, an equal number of mealworms were run with the maze facing in each of the four major directions.

The subjects of the experiment were 766 mealworms. They were sifted from their food about 15 minutes before being used. At this time they were placed in a large Pyrex dish under a 60-watt light bulb to increase their activity. Any mealworms which showed signs of pupating, molting, general lethargy, or size inappropriate to the maze were discarded.

There was a well-defined procedure for conducting the run of each mealworm. The mealworm was placed by means of tweezers in the beginning of the alleyway, and a glass cover was placed over the entire maze. A line was drawn 1½ cm from each turn. Any mealworm which rolled on its side from this point into the turn was discarded. Also eliminated were mealworms which took longer than 30 seconds to complete the run or more than 5 seconds to make a choice.

In order to insure that the behavior of the mealworm at the T-choice was not affected by the alleyway, some tests were conducted with just the "T" part of the maze. It could be expected that right and left turns would be made in about a 50–50 ratio. The results obtained by running 256 mealworms confirmed this expectation.

In the experiment proper, the results supported the findings of previous experimenters. Forcing the mealworm in one direction increased the chance that the subsequent choice would be in the opposite direction. The number of turns in the predicted direction decreased as the distance from the forced turn was increased. When the distance was 3 cm, 83% of the mealworms turned in the predicted direction, whereas only 66% did with a distance of 6 cm.

This experiment seemed to show that the centrifugal swing hypothesis was not the complete explanation for the behavior of mealworms in the maze.

Location of the Humidity Receptor of Mealworm Beetles and of Mealworms

The ability of mealworm beetles to respond to differences in humidity raises the question of how the beetle is able to detect these differences. Pielou[5] conducted a series of experiments to determine the location of the humidity receptors.

Since the antennae seemed a likely site for such receptors, they were removed and the reaction of the beetle was then observed in the humidity chamber. In the first series of investigations, ten of the eleven segments of each antenna were cut off. Eight experiments, involving 40 beetles, were conducted on beetles treated in this way. The same ex-

4. Grosslight, J. H. and Harrison, P. C., 1961. "Variability of response in a determined turning sequence in the mealworm *(Tenebrio molitor):* An experimental test of alternative hypotheses." *Animal Behavior,* 9:100–103.

5. Pielou, D. P., 1940. "The humidity behavior of the mealworm beetle, *Tenebrio molitor:* II. The humidity receptors." *Journal of Experimental Biology,* 17: 295–306.

periments were carried out concurrently with normal beetles. The antennae amputation caused no obvious ill effects on the beetles. However, it completely abolished the reaction to humidity and there was no recovery even after several weeks.

Having established that the receptor was located on the antennae, experiments were designed to further localize the receptors. The intensity of reaction was measured when various numbers of segments of the antennae were cut off. After removal of seven pairs of segments from the antennae, a significant reaction to moisture still occurred. But when eight were removed, the intensity of the reaction was greatly diminished. Thus, it seemed that the organs for the reception of humidity were located principally on the eighth segment. Microscopic examination of the antennae revealed that they were covered with five distinct types of hair-like structures. Further investigations showed that two of these types were involved in the detection of moisture.

Roth and Willis[6] experimented with mealworm larvae to locate their humidity receptors. Mealworms, like mealworm beetles, usually collect in an area of low humidity. With one of the three segments of the antennae amputated, mealworms behaved almost normally; but when two segments were removed, the mealworms no longer showed significant preference for low humidity.

Development of Mealworms Fed on Different Kinds of Sugar

A number of nutritional experiments have been done with mealworms. In one investigation, Fraenkel[7] studied the effect of 25 different sugars on the development of mealworms. Mealworms raised on glucose, maltose, dextrin, starch, and glycogen developed more rapidly than those fed mannitol, cellobiose, trehalose, melibiose, melezitose, and raffinose. Mealworms failed to grow on arabinose, xylose, rhamnose, ribose, fructose, mannose, galactose, sorbose, sorbital, dulctal, inulin, cellulose, alpha-methylglucoside, and alpha-methylmannoside.

Mealworms seem to have definite dietary requirements. They, as most animals, are probably able to select the foods which have the greatest nutritional value.

6. Roth, L. M. and Willis, E. R., 1951. "The humidity receptor of the mealworm, *Tenebrio molitor.*" *Journal of Experimental Zoology,* 17:451–488.

7. Fraenkel, G., 1955. "Inhibitory effects of sugars on the growth of the mealworm, *Tenebrio molitor.*" *Journal of Cellular and Comparative Physiology,* 45:393–408.

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