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Off to the (earthworm) races: A quick and flexible laboratory experiment for introductory zoology courses.

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A Quick & Flexible Lab Experiment for Introductory Zoology Courses

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Balancing the conflicting educational goals of content breadth versus content depth challenges teachers of any lecture or laboratory course. As instructors of an introductory zoology course, we wanted our students to experience the scientific inquiry process, not simply the outcome (e.g. Sundberg & Moncada 1994; Stukus & Lennox 1995; Adamo & Gealt 1996; Glasson & McKenzie-Woodrow 1997; Herreid 1998; Switzer & Shriner 2000). Thus, our goal has been to include hands-on, investigative activities in our laboratory sessions. Although we require research projects outside of class (e.g. term projects), we, like others teaching similar courses, faced a difficulty implementing active learning exercises within short laboratory periods. For our laboratories on specific taxa, students need to recognize characteristics, identify structures, and understand the functional morphology of that group. In view of these objectives, many investigative exercises are not amenable to the time limitations of our scheduled lab sessions. However, prudent choice of study species and directed working hypotheses should simplify the exercise enough to fit available time, reinforce taxon characteristics, and provide students with experience in the "process" of science.

With these ideas in mind, we developed a noninvasive experiment on an animal that is easy to obtain, easy to manipulate, and with which students are familiar: earthworms (Class Oligochaeta; Phylum Annelida). Earthworms are a tractable species and are often subjects of laboratory experiments (e.g. Vogel & Wainwright 1969; Hill 1976; McCallister & McCallister 1996; Dyche 1998). Our behavioral experiment tests the hypothesis that substrate texture affects earthworm locomotor ability. Our exercise takes approximately 30 minutes to complete (not including the pre-experiment explorations). Below, we provide background on earthworm locomotion followed by detailed aspects of our laboratory exercise.

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Background on Earthworm Locomotion

For detailed explanations of earthworm locomotion, we refer readers to invertebrate texts (e.g. Brusca & Brusca 1990); here, we review pertinent highlights. Earthworm locomotion is possible through the interaction of muscles (circular and longitudinal), a fluid-filled body cavity (the coelom), segments (metamers), a nervous system (ganglia in each segment), and "anchors" (their short bristles, or setae). With segments partitioning the coelom and segmental ganglia lending local "control," earthworms have the ability to contract or relax the muscles within a specific region of their body. Contraction of the circular muscles causes a segment to lengthen and thin, while contraction of the longitudinal muscles causes a segment to shorten and thicken. To move forward, an earthworm contracts its circular muscles and extends the anterior portion of its body. To bring the rest of the body forward, earthworms relax the circular muscles and contract the longitudinal muscles of a region, which press the setae into the substrate. Without the friction provided by setae, the earthworm would make no progress when it contracts the longitudinal muscles to bring the body forward behind the head. Thus, the interaction of setae with substrate is a key component of the locomotion process.

The process of locomotion in earthworms can be compared with locomotion in other commonly available study animals such as nematodes and bivalves (clams). Nematodes lack segments (i.e. have no segmental control), have no "anchors," and possess a coelom but only longitudinal muscles. Bivalves contract their muscles against blood instead of coelomic fluid, have circular and longitudinal muscles, use their shell and foot as anchors, but like nematodes have no segments. By thoroughly understanding earthworm locomotion, students will be familiar with components and processes necessary for locomotion itself.

Earthworm Laboratory Exercise

Pre-Experiment Explorations

Prior to the experiment, students conduct several activities designed to provide necessary background knowledge for the experiment. For example, they have a laboratory earlier in the semester covering basic principles of experimental design. In addition, students complete a pre-laboratory assignment requiring that they describe the structure and function of setae. Then, during the annelid laboratory, students observe and describe earthworm movement and manipulate a water-filled balloon. The balloon manipulations model 1) the action of circular and longitudinal muscles on the coelom and 2) the effect of "segmentation" (i.e. they twist the balloon into two parts and repeat the muscle contractions).

Hypothesis Development

At the beginning of the experiment itself, the instructor guides the class in reviewing the important components of earthworm locomotion. In particular, we clarify the role of setae in anchoring the worm. The instructor then asks a question such as, "What characteristics of a substrate would you expect to be best for earthworm locomotion?" Students quickly propose the substrate would need to have texture for the setae to work. The students are then asked to phrase this idea as a hypothesis, which usually yields a statement such as, "Earthworms will move faster on rough surfaces."

Study Design

Armed with the hypothesis, we then guide the students through a series of steps to generate the experimental design. First, students propose what general materials they will need to test their hypothesis; typically they suggest worms, a ruler, a stopwatch or clock with a second hand, and a smooth and rough substrate (specific materials are listed in Box 1). Second, the class discusses design details such as sample size (e.g. how many worms are necessary) and necessary controls. For example, we use white enamel pans (e.g. those used for dissecting or invertebrate sampling) for our "smooth" substrate and slightly wet the surface to further decrease friction. The rough substrate is created by placing a wet paper towel in the pan; we wet the paper towel to control for the possible effects of water. Third, the class confronts how to record the location of a worm in a consistent manner (e.g. a worm may move its anterior portion without moving the rest of its body). Usually, students suggest using the clitellum (the conspicuous band of tissue located approximately one-third of the way from the anterior end). Finally, we discuss the details of the measurement process. Students use probes to mark the location of the clitellum every 10 seconds for 30 seconds and then measure the distance between the probes. Our experience has indicated that 30 seconds is sufficient to yield variability in the recorded distances while 10-second intervals allow for short term changes in movement to be recorded.

Analysis & Assignment

All student groups combine their data, allowing each student to test fewer worms (which saves time) but generating a sufficient sample size to test the hypothesis. Prior to the end of the laboratory, we briefly discuss general concepts necessary for appropriate data analysis (e.g. What are the units of "speed"? What are the dependent and independent variables? What type of graph will be appropriate?, etc.).

The assignment then requires students to analyze and graph their data and answer a series of questions. We ask them to explain whether their data support or reject the hypothesis, and discuss the possible biological reasons for their results. We also ask them to identify problems with the design and/or execution of the experiment, to explain the potential consequences of each concern (i.e. could the problem alter the conclusion or does it just increase variability?), and finally to propose appropriate solutions. Oddly, in our estimation, a strength of the experiment is that many problems exist, helping students think critically about experiment design. For instance, the worms are different sizes, which may affect speed. In addition, student groups likely differ in how they conduct the experiment and may vary in the amount of water used, the light levels present at their station, their ability to accurately measure location, and how much they "care" about obtaining accurate results.

Extensions & Conclusions

Clearly, this experiment, as we conduct it, is not a completely open-ended, investigative exercise. While students are involved in all aspects of the design, the instructor gives a great deal of guidance. However, we have found this approach gives students experience with the scientific process while allowing us to address other aspects of the phylum. For less constrained instructors, the experiment could be easily adapted to permit students more independence. For example, as an assignment, instructors could cover earthworm locomotion prior to the laboratory and ask students to outline an experiment that they could feasibly conduct within a laboratory period. Subsequently, instructors would give students feedback on their outlines and provide an assortment of necessary materials in the laboratory. Students would then conduct their experiment and analyze their results. Alternatively, if time allowed, the whole process (question through execution) could be conducted during one laboratory session. In any case, we believe this experiment will work in modified form at a variety of levels (e.g. high school biology courses) or in other courses (e.g. in a general biology laboratory on "experimental design" or basic statistical analyses).

In our experience, the experiment is effective in a number of ways. The exercise reinforces what students have learned about experimental design and the process of science, and we have found that students have performed well on exam questions concerning locomotion. Finally, students seem to enjoy the laboratory, even to the extent that we have to (jokingly) discourage betting and their "encouraging" worms to move quickly. So, if you are looking for a quick and easy hands-on exercise to fit into your laboratory, consider racing some worms!

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BOX 1.

Suggested materials for conducting earthworm races.

- Earthworms ("red wigglers" or small garden earthworms work better than "night crawlers")
- Large, rectangular pans (Pyrex® baking dishes or white enamel pans)
- Paper towels
- Dissecting probes
- Water bottles filled with deionized water
- Small ruler
- Clock or watch with a second hand