An Investigative Look at the Biology of Invertebrates

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Abstract: Many introductory laboratories on invertebrate biology focus on a broad spectrum of phyla. Frequently, students examine preserved specimens and are only passively involved with the material. Here we introduce an investigative alternative. Student groups each focus on a living representative of a phylum. They pose questions about the animal, and develop and test hypotheses to answer them. They conduct library research and prepare presentations about their phylum. In this way, students learn from each other and gain experience with hypothesis development, testing, library research, and presentation of experimental results. This exercise is suitable for majors' and non-majors' introductory biology courses.

This lab is dedicated to Charlie Drewes, whose help, insight, and inspiration was instrumental to its development.

Introduction

Many undergraduate laboratories on invertebrate biology focus on a number of specimens across a broad spectrum of phyla. Frequently these traditional approaches to invertebrate biology consist of having students examine a large number of preserved specimens, and may include a dissection or two. Aside from the dissections, students in these labs are only passively involved with the material and frequently view the experience as an exercise in memorization.

Here we introduce an investigative alternative to the more traditional approach. Student groups in this two-part exercise each focus on a living representative of a phylum in the first week of the lab. They pose questions about the biology and behavior of the animal, and develop and test hypotheses to answer them. Each group then conducts independent library research outside of class and prepares presentations about their phylum to present to the other students during a subsequent laboratory period. Students use the information provided in these presentations and the question and answer period that follows to compile comparison data tables for the phyla. In this way, students learn from each other about the phyla covered in the exercise, gain experience with hypothesis development and testing, data collection, library research, and the presentation of experimental results.

This laboratory exercise is suitable for both majors' and non-majors' introductory biology courses. It can be performed in two or three 3-hour laboratory sessions, depending on whether the instructor wishes to use part or all of a preliminary laboratory period for the selection of phyla and preliminary literature research. Preparation for the investigative portion of the exercise requires preparation 4 – 5 days in advance, to set up the brine shrimp cultures, and 1 – 2 days in advance for the populations of the other study organisms.

Student Outline

Objectives

After completing this exercise, you should be able to:

1. Conduct a library search for information on the biology of invertebrates
2. Compare body form, methods of locomotion, feeding behavior, and reactions to stimuli among representatives of invertebrate phyla
3. Formulate hypotheses and design experiments to answer questions on different biological aspects of invertebrates
4. Effectively synthesize information to communicate your findings to others

Introduction

This is a two-part lab exercise in which you will investigate different biological aspects of invertebrates. Invertebrate animals are a diverse group encompassing an enormous range of organisms that differ in form, behavior, habitats, physiology, and structure. There are 35 phyla of invertebrates (comprising more than 95% of all animal species), and some of these phyla contain very large numbers of species. Because of this incredible diversity even within taxonomic groupings, it is not possible to examine all phyla. Instead, we have chosen 6 phyla that offer "user-friendly" creatures with an unusual combination of biological features and functions that can be easily observed.

Working in groups, you will become an "expert" on one phylum then teach other students about your phylum. In turn, you will learn about the other phyla from other students. At the end of this exercise, we want you to appreciate the truly remarkable diversity within invertebrates. In the first lab, each group of 3 – 4 students will investigate one species of a phylum. You will investigate several aspects of the animal's biology, including locomotion, reaction to different stimuli, feeding, and body form. Then you will do some secondary research to find out more information about your taxon.

In two weeks, each group will present their findings to the class to teach other groups about your phylum. Others will take notes and ask questions to clarify knowledge. Then you will work on organizing the information into tables so that you can compare the phyla researched by all of the groups in the class. You will be tested on the information from all groups.

Establish groups:

Get into groups of 3 – 4. Write down everyone's full name, email address, and phone number, because you will have to get in contact with them outside of lab. Establish times outside of lab when you can all get together for at least 1-hour at a time. If that is not possible, you should not be in the same group. For today's lab, divide up jobs. For example, when observing behavior have two people observing while one person times events, and another person takes notes.

First Lab: Primary Research
For this lab, you will work in a group of 3 – 4 to record observations on live and preserved specimens of one species of invertebrate.

- First study and take notes on the anatomy of preserved specimens. Make use of the textbooks on the lab benches to delve farther into your study organism.
- Then make observations on body form while organisms are undisturbed. Use the preserved specimens and slides to help you identify the body form.
- Next, make observations and perform experiments on feeding behavior, locomotion and sensitivity to environmental stimuli. As you design your experiments, include all elements of an experiment: identify the variables (independent, dependent and controlled) and decide upon the control treatments, number of replications and the number of individuals you would like to use to test your hypothesis.
- Write your hypothesis in form of a statement, not a question. A statement can be tested but a question cannot.
- Use the scientific investigation exercise sheet (Appendix A) provided at the end of the lab to help you work through your scientific investigation.

Your instructor has assembled some supplies on the lab table which you may use in your experiments, as needed. Additional material may be available for you to use. Check with your instructor.

Study body form

- First familiarize yourself with the anatomy of your organism by studying the preserved specimens, if available, and reading materials.
- Refer to the information below and determine its body plan, symmetry, whether it is segmented and what tagmata are present, if any.
- Count appendages and speculate on their different functions.
- Complete the "critter sheet" in Appendix B at the end of this lab.

Body plan: The body plans (animal body form) seen in invertebrates today are as a result of ancestral history, habitat and way of life. Invertebrates exhibit one of the three basic types of bodies. 1) **No body cavity** (acoelomates), where the body is an irregular form, as in sponges, 2) **a saclike body plan** characterized by a single opening, the mouth which empties into a gastrovascular cavity. The body cavity in these organisms develops between the mesoderm and endoderm or 3) **a tube-within-a tube design** (coelomate). A tube-within-a tube plan has a mouth at one end of a tubelike digestive tract and an anus on the other end and the body cavity is completely lined by mesoderm.

Symmetry: Symmetry refers to the correspondence in size or shape of parts of the body on opposite sides of a median plane. Invertebrates may exhibit **asymmetry**, **radial symmetry**, **bilateral symmetry**. Asymmetrical organisms have no clear regular arrangement of body parts. Radially symmetrical animals have similar parts radiating from a central axis. They can be divided into two similar halves in multiple ways. Bilaterally symmetrical animals can be divided into two mirror parts by only one plane passing through the longitudinal axis. That is, they have right and left parts of the body. Bilateral symmetry was a major evolutionary innovation because these animals are much better adapted for directional (forward) movement than are radially symmetrical animals.

Segmentation and Tagmosis: In some bilateral animals, the body is formed by a series of **segments**, repeated units down the length of the animal. Sometimes, the segments fuse or develop different shapes in different regions of the body so that the body becomes divided into distinct regions specialized for different functions. These distinct regions of the body are call **tagmata** (singular, **tagma**). For example, a head tagma may specialize for search and consuming food. A thorax (thoracic tagma) may be specialized for locomotion in many invertebrates or for heart and lung function in vertebrates. An abdomen (abdominal tagma) may be specialized for digestion of food and reproduction.

Sometimes tagmata fuse later in evolution. For example, in spiders the head and thorax are combined into a single tagma, the cephalothorax (cephalo = head). In ticks, which are related to spiders, the abdomen has also fused with the cephalothorax, so the body has no externally visible tagmata.

Identify the tagmata in your organism and deduce how many segments form each tagma. Note in the next paragraph that each pair of appendages indicates a segment.

Appendages: Bilateral animals may have a pair of appendages per segment. Early in evolution, those appendages were walking legs, but as body regions became specialized, so did the appendages. Legs may be modified into antennae, mouthparts, claws, flaps for swimming, mating structures, etc. Or the appendages may be lost from some segments. Count the appendages on each tagma of your organism and deduce their functions.

Organisms for study

Each group of 3 – 4 students will study one of the following examples of invertebrates. Organisms will be drawn at random. Then groups may switch to any organism not assigned.

- Hydra (Phylum Cnidaria, Class Hydrozoa): Hydras are small whitish organisms mostly located at the bottom of the stock container. However, a few individuals can be seen floating in the water if the container is disturbed. Use a transfer pipette to gently detach and move a hydra. If the organism becomes lodged in the transfer pipette, add more water in pipette and try to dislodge it. Make sure the Petri dish has aged water at all times.

- Planaria (Phylum Platyhelminthes, Class Turbellaria): Planaria are free-living aquatic flatworms. Planaria are very delicate and tear easily. Move Planaria gently by lifting with paint brush.

- Rotifers (Phylum Rotifera, *Philodina* sp.): Rotifers are small whitish organisms swimming in the stock container. Use a transfer pipette to transfer rotifers. If the organism becomes lodged in the transfer pipette, squeeze pipette in water to try to dislodge it. Make sure they are in aged water at all times.

- Blackworms (Phylum Annelida, Class Oligochaeta, *Lumbriculus variegates*): These are relatives of earthworms. Use only pipettes to transfer worms from the stock container. Do not handle or transfer them with forceps. This will injure the animals. Allow at least 1cm of aged tap water for underwater experiments.

- Pond snails (Phylum Mollusca, Class Gastropoda, lung-breathers from families Physidae and Limnaeidae): If snails are quiescent, get them moving actively before the start of the experiment by immersing them in lukewarm water for a few minutes. Once a snail shows signs of activity, move it from the water and dab dry with paper towels. During the experiment, handle the snails **gently** especially when lifting them from attached substrate.

  There are a couple of glass slides on the bottom of their bowl with algae growing on them. You can try getting them to graze on the algae, then invert the slide under a dissection scope to see the mouth and scraping radula. It may take several attempts before the snails successfully adhere to the slides as you invert them. But you can watch how they move to right themselves if they fall off. Or you can watch them graze along the sides of the bowl they're kept in. If you look closely, you can see them opening and closing their mouths, and using their radula to scrape algae from the sides of their container.

- Fresh-water Mussels (Phylum Mollusca, Class Bivalvia, *Corbicula sp*.): These are introduced from Asia and are a pest species. They like to burrow with just their incurrent and excurrent siphons exposed. First see if you can find their siphons in the aquarium. To see locomotion, you will need about 1 cm of sand in a fingerbowl for them to burrow in.

  To see feeding, put a clam in clear water and a little sand in a glass bowl. Make some dark blue water with food coloring. Fill a plastic pipette with the colored water and put the end very close to the incurrent siphon. Very slowly release a stream of colored water, bit by bit. If you do it slowly enough, you can see it entering the siphon. Occasionally they "spit" it out, but not often. Every now and then, you can see some exiting the excurrent siphon.

- Crayfish (Phylum Arthropoda, Class Crustacea, *Cabarus sp*.): Crayfish must be handled with care. To pick one up, approach the crayfish from behind, grasp it firmly but gently on the carapace (body shell) just behind the pincers. Do not panic when it tries to reach you; it will not be able to. Keep the crayfish moist and cool. Keep a cover on the container when not working with crayfish, otherwise, they may escape. When observing feeding, locomotion, and response to stimuli, be sure to note and record exactly which sets of appendages are involved in each behavior.

- Mealworms/Darkling beetles (Phylum Arthropoda, Class Insecta, *Tenebrio* sp.): As in many insects, the immatures and adults have different forms, habitats and foods. Study the dead adults for body form and appendages. You can study feeding and locomotion in both the larvae and adults. Mealworms do not bite. Do not squeeze them when you pick them up.

- Sowbugs (Phylum Arthropoda, Class Crustacea, *Armadillium* sp.): These pillbugs get their name from their habitat of rolling into a ball when bothered to protect their soft internal body parts. They are terrestrial crustaceans that are found in damp, moist, dark habitats during the day. They are active mostly during the night.

First, Observe Behavior

READ FIRST – Working with live animals: National regulations stress that animals used in research must always be handled with humane care. From an ethical point of view, you are responsible for the humane treatment of animals, and for minimizing pain and discomfort during the experiments. From a scientific point of view, the treatment and handling of animals may strongly affect their behavior. Therefore as you study invertebrates you should:

- Handle the animals as little and as gently as possible
- Do not subject the animals to undue stress, for example, extreme temperatures, light, etc.
- Do not cause unnecessary disturbance when near the animals, for example, no bumping or banging items on the bench
- Working with living organisms offers another challenge. Most of the time, animals may not be responsive to the stimuli. Additionally, most of their behaviors are subtle and may go undetected. Therefore, you need to bring to this lab an inquiring mind, keen eyes, patience, and ingenuity.

Always start with careful observations of undisturbed animals.

- Spend at least 10 minutes just observing your animal without disturbing it. Write down what you observe. This is called *ad libitum* sampling, where the observer records all behaviors as they occur (e.g., field notes). It's useful for initial observations on a species new to the observer, or as a first step to identify an appropriate research topic, or formulating a hypothesis. Describe each behavior in detail. Note which body parts are involved. If a set of appendages are involved, specify which ones.
- Generate questions and hypotheses about what is happening. Write those down. Check with your instructor to make sure: 1) that you are testing a hypothesis that can be completed within the lab period and 2) that the required supplies are available and 3) you will not be harming the organism in any way.
- After recording the *ad libitum* data, select a specific behavior and choose a hypothesis about it that you think you can test. Plan how you will do that and for how long. Be sure that your observation period is sufficiently long so that you will be able to observe numerous incidences of the behavior.
- Decide how you will record your data in advance. You can describe what you observed in words, for example, "When one prods a blackworm's tail, the worm suddenly and repeatedly twists its body into a helical or corkscrew-like shape." But also be *quantitative* – that is, *count types* and *number of behaviors, duration of behaviors, magnitude of behaviors,* etc. Recording quantitative data is usually easiest if you design a data sheet before you begin. You might decide to include a list of potential behaviors as the first column of a table and record start and stop times for that behavior in the second and third columns. Another member of the group might devise a similar table, but instead of stop and start times, have columns broken into 1 minute intervals (minute 1, minute 2, etc.) and place a tick mark in the column every time a particular behavior occurs during that minute. In that manner, a group will be able to report not only which behaviors they observed, but also the duration of the behaviors and the number of times that they occurred during specific time intervals.
- Write down your methods and draw up your data sheets prior to starting.

- Then, *record in detail* what happens during your observation period. *Use the scientific investigation sheet provided at the end of this lab in Appendix A help you plan these exercises.*
- Individuals vary. What one does may not be typical. So repeat your experiments on as many animals as possible. If you move an animal to a new location, allow it at least 10 minutes to acclimate before performing experiments on its behavior. Always write down detailed observations and data. To maintain consistency in your data, observe each animal for the same length of time.

Second, Study Feeding Behavior

What do invertebrates eat? How? They may be carnivores, herbivores or omnivores, filter feeders, or detritivores. Virtually all must interact with the prey species. Such an interaction usually requires (1) production of sensory cues by the prey; (2) detection of the prey by the predator; (3) an attack by the predator, (4) escape or defense by the prey, and (5) feeding if the attack was successful. How successful the predator is at sensing, chasing and capturing the prey and how good the prey is at defending itself, escaping, or hiding, depends on evolutionary adaptations each possesses.

- Observe how your organism finds and eats food. Organisms may not feed if they feel threatened. So disturb the unfed specimens as little as possible. (Note: they may be sensitive to vibrations from your lab bench).
- Pose a question and hypotheses. Write them down.
- Plan and carry out food choice experiments. Write your planned methods and design your data sheets as described above under step one.
- Carefully observe and record in detail the organism's responses and feeding. Consider what sensory cues may be involved in locating the food.
- Revise your methods if necessary and try again.

Be quantitative; time, count, measure, how often, how big, how long, etc. Repeat your observations with as many individuals as possible.

Third, Study Locomotion.

Invertebrates use many different modes of locomotion. Some fly, others crawl, swim, creep, walk, jump, or even run. Yes, invertebrates can run! Can you think of an invertebrate that runs? Interestingly, some species are capable of more than one mode of locomotion. For example, a grasshopper can jump, walk, or fly. Different structures can be used to perform the same locomotion function. For example, a springtail, which is a small insect 1-3 mm long, can jump long distances using a specialized organ located at the base of its tail. On the other hand, many insects can jump using their legs. Nevertheless, locomotion behavior may impact on an organism’s food gathering and predatory techniques and hence, is of great importance to an animal’s success in its environment.

- Observe how your organism moves. Is there just one way, or several? Are some faster than others? Do different stimuli or circumstances produce different modes of locomotion?
- Pose and explore your own questions. Write your hypotheses and methods and design you data sheets.
- Record detail observations and quantitative data.
- Repeat your observations with as many individuals as possible.

Fourth: Study Reactions to Stimuli

If time allows, explore how your animal responds to light, temperature, gravity, threat, chemicals in the water, or some other factor that interests the group. If you do not get to perform this experiment, you are still required to find out from literature how members of this phylum including your organism respond to different stimuli.

Independent Work – Secondary Research

Outside of lab, group members will research their phylum in the textbook, library, and on the internet to report to the class. Groups may focus on a particular class or order within the phylum. That is especially important for those studying arthropods or mollusks. Talk this over with your instructor.

Each member will investigate a different aspect of the taxon. Groups will coordinate their findings so that members don't give repetitive information in their presentations. Individuals do their own library research and type a bibliography of their sources used, using APA format. Use only *scholarly* sources (textbooks and journals) for background information as necessary.

Among the things to find out are the following:

1. What characteristics define the taxon? That is, what do all of these very diverse species have in common that members of other phyla lack?
2. Photographs of your organism and other members of the phylum, showing how different members of the same phylum can look.
3. Body structure: symmetry, segmentation, tagmosis, appendages, locomotion, reproduction. Other interesting features.
4. How different members of the same phylum, including your study organism, live. What do they eat? Where do they live?

After completing their research, group members should get together and develop the presentation. Although each group will only have one presentation, every group member will present findings of their own research. The presentation must be of uniform format with the bibliographies combined. Place the bibliography as your last slide. *Every group member must participate* in this process. In the end, each group member will evaluate other members' participation *anonymously*. Your final mark will be based on: 1) basis of material discussed, its thoroughness, quality of the presentation, 2) your group evaluations, and 3) individual presentation. This means that if you do not participate in this project and prepare yourself for the presentation (i.e., by knowing your section), you can receive a *zero grade* for this assignment.

What to include in the presentation

The following must be included in your presentation (given in parenthesis is the maximum number of slides you are allowed to have for each section).

1. Introductory slide with full names of team members, and title of the presentation. Make it an interesting and informative title (1 slide).
2. Information on natural history/taxonomy and body form of your organism from the critter sheet provided at the end of the lab. This is the only introductory information that should be on your slides (2-3 slides).

3. Experiments you conducted-on behavior, locomotion, feeding and response to stimuli (6 – 10 slides). Include for each experiment you conducted:
    a. Question/hypothesis you tested.
    b. Brief description of the methods.
    c. Summary of your results.
4. Conclusions, including whether you accepted or rejected the hypothesis:
    a. Discuss whether your findings are unique to your specimen or universal to all members of the phylum.
    b. Discuss any limitations in your experiments, problems, future research and ways in which you could improve upon the experiment.
5. Literature Cited – provide references in a consistent bibliographic form following the APA style.

Note: all pictures copied from the internet must have website address and authors. No presentation should exceed 16 slides!

Second Lab (in two weeks): Presentations and Summaries

Each group will give their presentation, while others take notes. After each presentation, listeners must ask questions to clarify and extend their knowledge. At end of class, turn in the following: presentation (the actual PowerPoint on CD), your completed group evaluation sheet, critter sheet and scientific investigation sheet.

Presentation Guidelines

- Maximum length of time for each group is 20 minutes with 5 minutes for questions.
- Make a PowerPoint presentation of uniform style.
- Present only the most important, most interesting stuff. Masses of facts get really boring! You should know far more than what you present. That knowledge will show in how you answer questions after your talk.
- Organize your presentation in a logical sequence. Make sure there is flow and fluency. Know what you are going to say and how you are going to say it.
- Don't put a lot of words on a slide – just key phrases and important words that your audience won't know how to spell.
- Don't use unnecessary noises or movement in the slides. This is a science presentation and not a demonstration of your animation skills. Excessive animation distracts from your talk and is not acceptable in a professional presentation. *Keep it simple.*
- Find pictures that explain concepts.
- Use the internet as a source of good, color pictures of representative members of your phyla to include on your presentation slides. Be sure to credit your source by including the web address at the bottom of each picture.
- Master your topic. When preparing for your talk, you are expected to be the "expert" on the topic. This means that you have to know more about the topic than what is included in your presentation.
- Practice your parts to make sure you, a) don't repeat each other's information, and, b) are within your 20 minute total time limit for the entire group.

- Practice talking to your audience, not at the slides. DO NOT just read slides!
- Practice speaking *slowly* and pausing regularly, to allow students to take notes.
- All students in a group are required to participate equally with every member presenting their own findings (see group evaluation forms).
- Audience members should hold their questions until the end of each presentation, then ask.

Further tips on presentations are given in Appendix C. Appendix D contains an explanation of how your presentation will be evaluated by your instructor.

Organizing and Summarizing the Information

After all groups have presented, each person is responsible for organizing the information from all presentations into a comparison table. Comparison tables put comparable information side-by-side so that comparisons between the phyla can easily be made.

There is no one right table. We design tables to tell us what we want to know or to highlight certain kinds of comparisons. Begin by making a list of organisms to compare. Then make a list of the characteristics of those organisms that need to be compared. These become the rows and columns of your table.

Work as a group. Your instructor will help you in this process.

Notes for the Instructor

Introduction

This lab works best when students are given the chance to pick their study organism a week prior to conducting the experiments. Organisms are drawn at random. However, we have tried it with students picking the organism the same day as their experiments. Three to four students per group is best for having all students fully involved, but depending on class load and finances, larger groups may be necessary. If your class size is large, you can add other organisms to the list. Maintaining a large number of crayfish even for a few days can be problematic and very tedious. We recommend substituting them with other organisms that are easier to care for if you have a large class. Other organisms we have tried with success include crickets, pillbugs, and cockroaches. You can also have two groups work on mollusks (e.g. snails and clams) or two groups work on arthropods (e.g. crustaceans and insects).

A suggested time line for this lab is as follows:

- Week 1: assign critters to groups, hand out critter sheets, have students begin background investigations using outside resources, and begin designing their experiments
- Week 2: conduct experiments (Lab 1)
- Week 3: student presentations (Lab 2).

If your class has several sections, it is important to spend the time training your teaching assistants. The following are some issues you need to discuss.

- What constitutes human treatment and ethical handling of animals.
- Proper way of handling the animals during the experiment. TAs should be comfortable working with all the animals present.
- Effective and creative ways of developing hypotheses. If time allows, ask the students to send their ideas/hypotheses to their respective instructors before conducting the experiments.
- TA's attitude is important for the successfully completion of this lab. Encourage your TAs to be positive, to be excited about the experiments and emphasis the critical skills students will acquire from doing this lab. If students can understand the benefit of an exercise, they are more likely to approach it with a positive attitude.
- Marking issues. We normally show TAs several presentations from previous years. We then evaluate these presentations as a group, trying to come to a consensus.

Advance Preparation for Lab 1

If students are going to observe feeding behavior, some of the specimens should be transferred to containers without food for 24 hours prior to lab. Containers should allow direct observation without disturbance. Students should be warned not to disturb these specimens before feeding.

Collect as many invertebrate text books from the library and bring them to the lab. Make the point that textbooks are a good entry into new topics. Other textbooks can be placed on the reserve library. We purposely limited the amount of information about specific phyla covered in the student handout in order to encourage student investigation using other resources.

Not all student groups will make it through the entire list of suggested experiments. Depending on their species, some may elect to spend more time examining a particular characteristic, for example, locomotion or feeding behavior. Some may design slightly more elaborate investigations, or test their hypotheses using a larger sample size. We've found that it's important to be flexible in our expectations so that the students don't feel too pressured to sacrifice quality of design and implementation in order to rush through a full list of experiments.

Specific details on care and maintenance of the organisms needed for this lab are included in Appendix E.

Secondary research

Student groups may feel rushed to do the library research, digest their data, and prepare a presentation in one week. Possible solutions: 1) a class period in the library, 2) another lab that doesn't require outside work inserted between the first lab and when they have to give their presentations, 3) allow the student groups to select their phyla representative a week or so prior to the lab and require them to do their background library research before the first week. This has the added advantage of familiarizing them with their animal in advance, so that they may feel better prepared to tackle the observations, pose their questions, and design their experiments once they get to lab.

Most students know how to find and download images from the web. For other information, have them look first in their textbook and an invertebrate zoology text. They may need some guidance with the library research.

Lab 2 - Presentations

We allow groups to give poster presentations instead of PowerPoint talks.

Bibliography

Scholars have to follow whatever bibliographic rules are set by editors, so students might as well get used to following examples in a particular journal or book.

Tables

The purpose of having students construct their own comparison tables is to make them actively use the information they have received and teach a valuable technique for organizing and learning information that many students do not know.

To teach this technique it is important that students decide on their own row and column headings. Novices often fail to give topics to the rows and columns and thus fail line up equivalent information in the same row or same column. This also allows the teacher to look over their shoulder and say if necessary, "Does what you've put in that cell deal with the topic of that row?"

Another valuable technique in making tables is to write as little as possible in any one cell. The more white space, the more readable and apparent the similarities and differences. Allow students to start with more words, but then show them how they can simplify. There is no one right table. So encourage students to develop tables for whatever they think would help them organize information.

Samples of possible table designs can be found in Appendix F.

Supplemental Research

In this lab, students gain more extensive experience with representatives of a few phyla than they do with a more traditional invertebrate lab exercise. To do so, however, we sacrifice some of the breadth of that experience. At Radford University, students are given an additional project to supplement their knowledge of invertebrate taxa. First, they were given a list of phyla on which they will be quizzed. They were also given instructions on how to locate pictures on the internet of diverse members of those phyla. They then built PowerPoint files for themselves containing the downloaded pictures as well as the hierarchical classification for each animal. They used randomized versions of this file from which to study. In lecture they took 10 minute quizzes on the material, which used a slide show of pictures that displayed for 30 seconds per slide, and ran twice. Students were asked to supply the organism's common name, the name of the phylum to which it belonged, or the hierarchical classification. For exams, the slide shows were set for 20 seconds per slides and looped continuously for the entire period.

The students were also responsible for learning the phylogenetic relationships and defining characteristics of each phylum by researching them within their textbook. They were quizzed on this information as well.

The specific phyla that were included in this exercise are listed in Appendix G.

Evaluations

We evaluate this exercise out of 50 points. Points are distributed as follows:

- Group Evaluations (30 points): Every individual in the group receives the same mark. These points are based on the quality of the presentation/accuracy and the experiment, presentation organization, and whether there was evidence of teamwork.
- Individual evaluations (10 points): Points are based on individual's oral presentation skills, whether they demonstrated knowledge of the subject, personal organization, and their abilities to respond to questions.
- Group member evaluations (10 Points): Group members evaluate each other. This ensures equal contribution of effort to the projects by all.

The number of points provided here are just a guide. You can vary this number depending on your circumstances.

Marking of the presentations

For large classes, marking is done by a panel of three instructors, two TAs and the class instructor. The class instructor attends all presentations and ensures that marking is done fairly and consistently across all sections. Most of the marking is done during the presentations. However, all students are also required to submit their presentation at the end. Further adjustment can be made on the basis of the submitted presentation, if needed. The final mark is the average of the three instructors' marks for a presentation.

Materials

Living organisms required for a class of 24 students working in groups of 4

- 1 culture brown hydra (Ward's Natural Science #87 V 2020 $5.25)
- 1 culture planarian (Carolina Biological Supply #13-2954 $6.95)
- 1 culture rotifers (Carolina Biological Supply #13-3174 $6.85)
- 1 culture blackworms (Ward's Natural Science #87 V 4680 $6.50)
- 1 culture brine shrimp (to feed to the hydra – Carolina Biological Supply #14-2226 $6.25)
- 1 culture mealworms (Carolina Biological Supply #14-4272 $6.50)
- 6 – 12 crayfish (can also be collected or bought from a local pet shop – Carolina Biological Supply #14-2510 $8.25 per pack of 3, or #14-2512 $31.50 per pack of 12)
- 6 – 12 pond snails (can also be collected – Carolina Biological Supply #14-1210 $10.95 for 6 each of 2 varieties)
- 6 – 12 freshwater mussels (*Corbicula* sp.). This invasive species can be collected or marine mussels can be bought at local fish markets. If buying marine species, ask the clerk for aged water for keeping them. (For purchased freshwater mussels – Carolina Biological Supply #14-1278 $5.75 for a pack of 3. Note: we had difficulty keeping the freshwater mussels we purchased alive. *Corbicula*, on the other hand, are very hardy).
- 1 – 3 cultures green algae (to establish cultures for feeding the mussels and snails – can be collected. Carolina Biological supply #15-1590 $20.80 for 4 cultures)

Materials available to all groups

- resource materials (e.g., invertebrate zoology and general biology texts, internet access if possible
- ~ 12 Depression slides & cover slips
- 4 Paint brushes manipulating/stimulating organisms
- Several liters aged water*
- Petri dishes, various sized bowls (for containing animals during experimentation)
- Aquaria
- 12 – 20 Plastic pipettes
- 12 Probes
- Ice to make cold chambers
- 10 Toothpicks (for picking up canned food if using)
- 6 Stopwatches
- Congo red (0.001g/10g H2) to stain yeast cells.
- 1 bottle food coloring (dark color best – for examining flow through incurrent siphons of mussels)
- 6 – 12 Digital hand counters
- 6 – 12 Capillary tubes
- 6 Forceps
- 3 – 5 Cardboard boxes (for making mazes)
- 3 – 4 Warming plates for temperature choice experiments
- 6 Lamps and/or fiber optic lights
- 1 Packet mixed colored paper (for making choice chambers of different colors)
- 1 Roll each colored cellophane of several colors (e.g., red, blue, green) to test light sensitivity
- 6 Thermometers
- 2 – 3 yards Black cloth or paper to make areas dark
- 6 Watch glasses
- 1 small bag of light colored sand (for substrate for mussels)

* Water in which to maintain cultures must be aged for 3 – 4 days before it can be safely used. However, another alternative is add a dechlorinating solution (available at pet stores), and a bubbler to the tank. The water will then be ready for in 4 – 8 hours.

Food items
- 1 can fish flakes
- 1 can goldfish sinking fish food pellets
- 1 can cat food
- a variety of carbohydrate, protein, or fat based foods (e.g., cat food, dog food, tuna, carrots, lettuce, potato, pasta)
- 1 packet yeast

Other materials groups may want for their experiments, e. g.
- 6 Y tubes for choice experiments
- 6 fiber optic lights to test phototaxis
- chemicals (e.g. salt, acid, alcohol) to test sensitivity

Materials for particular groups

Hydra (Phylum Cnidaria) group:
- Preserved slides of hydra, whole mount and cross section. Longitudinal sections would be ok also.
- Living brown hydra in stock container with food
- Living brown hydra without food in covered watch glasses or dishes. (Do not disturb!)
- Aged water
- White paper
- 3 – 6 dissecting microscopes
- Feeding materials: *Lumbriculus* fragments or brine shrimp.

Planaria (Phylum Platyhelminthes) group:
- Slides of preserved and stained *Planaria*. Whole mount and cross section.
- 3 compound microscopes
- Living *Planaria* in stock container with food
- Living *Planaria* without food in watch glasses or petri dishes
- White paper
- Source of light
- Feeding materials: *Lumbriculus* fragments or liver

Rotifers (Phylum Rotifera) group:
- White paper
- Source of light
- 3 compound microscopes
- Feeding materials: *Lumbriculus* fragments
- Colored yeast cells diluted to various concentrations

Blackworm (*Lumbriculus variegates*) (Phylum Annelida) group. (These are very small, but transparent, so internal organs are visible with a microscope. Other worms could be substituted.):
- 2 – 3 Preserved earthworms
- 10 Living black worms
- Clear plastic mm ruler
- Paper with 1 cm grid lines
- Tank of aged water
- Smooth wet glass
- Source of light
- Feeding materials: sinking fish flakes

Crayfish (Phylum Arthropoda) group:
- 2 – 3 preserved crayfish
- 5 – 10 living crayfish in separate containers
- Dipnet
- Aquarium
- Source of light
- Feeding materials: Planaria, whole *Lumbriculus* worms, sinking pellets etc.

Fresh water mussels (Phylum Mollusca) group:
- Shallow bowls
- Light colored sand – to fill small containers ~1" deep for *Corbicula*
- Aged or pond water
- Plastic pipettes
- Food coloring
- Beaker for mixing colored water

Pond snails (Phylum Mollusca) group.
Pulmonates: Physidae: *Physa gryina* (operculum on left facing you) and Limnaeidae: *Fossaria obussa*. (Also available from Carolina Biological: Mollusca: land snails, slugs, freshwater mussels):
- 10 living pond snails
- Hand lens
- Glass water container (to facilitate examination by students)
- 2 – 3 algae covered slides (for watching feeding – we make these by placing slides in a fishbowl or aquaria containing algae for several days to a week before lab)

Prepared slides & preserved specimens
- Hydra wm, cs, ls
- Planaria wm, cs
- Earthworm cs, ls, preserved
- Rotifer wm
- Preserved mussels or clams
- Preserved crayfish
- Preserved mealworm adults (pinned) and larvae

Acknowledgements

We gratefully acknowledge and thank Dr. Charles Kugler, emeritus professor of Biology at Radford University, for his considerable help in the development and testing of this laboratory. Thanks as well to Marielle Hoefnagels and Mark Walvoord whose "Conversion Immersion" workshop at the 2004 ABLE meeting in Bowling Green was the impetus for our decision to develop this exercise in the first place. We are also indebted to all of the participants of our 2006 workshop at Purdue, whose insightful comments were instrumental in improving the final product.

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Hickman Jr., C. P., L. S. Roberts, S. L. Keen, A. Larson, and D. J. Eisenhour. 2007. Animal diversity. Fourth edition. McGraw Hill Higher Education, Boston, Massachusetts, 480 pages.

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Note: Any Invertebrate or Zoology textbook can be useful resource.

About the Authors

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Appendix A

Scientific Investigation Worksheet

Group member names: ____

1. What are you investigating? Locomotion, feeding, reaction to stimuli.

2. What interesting observation(s) have you made?

3. What is the question to be studied?

4. What is your hypothesis? *(should not be a null hypothesis*)

   a) What is your dependent variable?

   b) What is your independent variable?

   c) What is the relationship between the independent and dependent variable?

5. Briefly describe your experimental design. A crucial step in designing an experiment is identifying variables and how you are going to quantify (measure) them.

   a) How are you going to measure the *dependent* variable?

   b) How are you going to measure the *independent* variable or how are you going to vary/change it?

   c) What are your standardized variables (these are factors that are kept equal in all treatments).

   d) What is your control?

e) How many times are you going to repeat the experiment (replication)?

f) What is your sample size (i.e. number of individuals used)?

g) Briefly describe the experiment.

h) Make a data table to record the data you collect.

6. Briefly describe your experimental findings. Did your results support or not support your hypothesis? Use the appropriate statistical procedures you've been taught to answer this question.

Appendix B

Critter Sheet

I. Natural History/Taxonomy:

- What is the common name?

- What is phylum name (class, order, family, genus, species)

- Name at least 4 characteristics that define this phylum. That is, what do all of these diverse species have in common that members of other phyla lack?

- Name three other familiar organisms that belong to same phylum.

- Describe the preferred microhabitat.

II. Body Form:

- Make a detailed sketch. Label key anatomical features that are evident.

- What is body plan? Is it acoelomate, pseudocoelmate, coelomate?

- What type of symmetry does it have? Is it asymmetrical, radial or bilateral?

- Is the animal segmented? About how many segments does it have?

- Is there evidence of tagmosis? Ho many tagma are present? Are they fused?

- How many appendages? Their functions?

III. Behavior experiments:

- Describe the pattern and mechanism of locomotion.

- Describe food preferences. What type of food does it eat?

- Describe reactions and responses to either to gravity, light, touch or temperature.

Appendix C

More Tips for a Successful Oral Presentation

The overall goal of an oral presentation is to communicate information effectively and efficiently within a specified time period. Your talk should have sufficient details to be informative and interesting and at a "level" appropriate to your audience (in this case your classmates). A presentation is different from a lab report in that your audience has only one chance to get the point. The audience appreciates a logically developed, well organized talk, without extraneous details, delivered clearly, smoothly and with enthusiasm.

The following are some guidelines that may help you prepare for your oral presentation.

During your presentation

1. Introduce yourself/group members.
2. Introduce the topic. There are two main purposes related to an introduction.
    a) Introduce the subject. What is your topic or title? For example, state your phylum or species of interest etc.
    b) Provide a framework for information that follows (let your audience know where you are taking them), i.e. an outline (overview) of what will be covered.
3. Explanation. This is the "heart of your presentation". Go over specific aspects of your study, for example, anatomy, body plan, locomotion, behavior etc.
    a) State specific questions/hypotheses investigated, explain testing procedures, and key results. Be brief and to the point. You do not have a lot of time to go into details. Explain any technical terms that your audience may not be familiar with. You can write these on the slides.
    b) Use figures and tables where necessary. Do not provide too much information on figures and tables. Use an easy to read font and large font size. Figures are preferred to tables in presentations.
    c) Explanation should be logical, clear, and concise with effective arguments supporting the results.
    d) In this exercise, remember to compare your organism to other members of the phylum.
4. Presentation etiquette.
    a) Do not read your slides to the audience. Have minimum text on the slides.
    b) Talk loudly and slowly, don't mumble.
    c) Don't rush. Avoid rushing by carefully selecting what to include in the presentation.
    d) Do not talk with your back to the audience.
    e) Make eye contact with your audience.
    f) Show enthusiasm about your topic.
5. Ending your talk.
    a) Bring your presentation to a close by summarizing major findings of your study and other interesting aspects of your phylum.
    b) Reinforce the major points and clearly state your "take home message".
    c) Acknowledge any people who gave you advice, or helped in any way.

After the presentation

You are required to answer questions from the audience after your presentation.

1. Answer questions as clearly and briefly as possible. If you do not know the answer to a question, admit it and move on.
2. Repeat every question so that the entire audience knows what has been asked.
3. Take time to answer and reflect on the question. Do not rush answering the question.
4. Ask for clarification if you don't understand the question.
5. Thank the audience for listening.

More helpful advice

For further information on giving effective PowerPoint and oral presentations, refer to page 294 of Pechenik (2004). Two websites highlighted on this page will be very helpful as you prepare for your presentation.

http://www.swarthmore.edu/natsci/cpurrin1/powerpointadvice.htm

http://www.kumc.edu/SAH/OTEd/jradel/effective.html

Appendix D

Presentation Evaluation Guidelines
Your instructor will evaluate your presentation for the following characteristics:

- Presentation format:
  - Introduction: Did you introduce yourself, your group, and the topic and provide an outline for your talk?
  - Time limit: Did you stick to the time limits?
  - Clarity: Was your presentation clear, readable, well laid out, focused, logical, and not overwhelmed with visual effects, distracting backgrounds? Remember: the simplest presentation style is usually the most effective.
- Content
  - Accuracy. How accurate was the information you presented? It is important to get your information from credible sources especially when you are using the internet.
  - Depth of presentation: Did you demonstrate knowledge and understanding of the topic and use peer reviewed studies to support your results and explain concepts?
  - Did you cover all required elements? Did you state hypotheses where necessary, and report on your procedures and results?
  - Project improvements: Were improvements and extensions to the experiment included in your presentation?
- Overall presentation style/skills. Was your presentation well paced and interesting? Did you speak loudly and clearly, make eye contact with the audience, use appropriate language, exhibit enthusiasm, and confidence? Were you well prepared? Was your PowerPoint presentation free from technical errors?
- Did you conclude your presentation?
- Use of visual aids. Were they readable, well laid out, focused, and appropriate to the topic?
  - Were they referenced?
  - Used to reinforce concepts?
- Were you able to answer questions? Did you deliver accurate responses to questions with confidence and explain points clearly?

Appendix E

Live Animals

Place orders for all animals except the brine shrimp to arrive 1 – 2 days before lab. Arrange for the brine shrimp to arrive 4 – 5 days before lab. Alternatively, you can buy the brine shrimp eggs and culture them yourself. You will need a plentiful supply. Note: you may want to collect the pond snails and *Corbicula* mussels yourself, rather than buying them. If you don't have don't have a plentiful source of algae available for feeding to the mussels, you'll need to establish a culture several weeks prior to getting the mussels. Be sure to order the algae cultures in sufficient time to establish good cultures. When they arrive, add them to aquaria or fish bowls filled with aged water and place them in a window to culture.

Instructions for locating and collecting these animals are given below.

Working with live animals

It is strongly suggested you clearly explain to the class what constitutes humane treatment of animals. You also need to set limits on what stimuli can be used and how much. Avoid use of strong acids and bases, hot water and loud noise. These precautions minimize the number of animals killed during the experiments.

Keeping live organisms

- Planaria – These don't have to eat for a week, but they need to have their water changed every day. Pour off the old water off, and add new aged water.

- Rotifers – Keep rotifers in the containers in which they were shipped. Transfer to small Petri dishes a prior to the lab. Let them acclimate for at least 15 minutes before use.

- Black worms – Place in a bowl with about 1 – 1.5 inches of aged water. Add a piece of brown paper towel. Feed with 1-2 sinking fish food pellets. Do not overfed. Use only plastic pipettes or an eyedropper to transfer these organisms. Forceps, hooks, metal probes should not be used. They injure very easily. Black worms can be immobilized for student investigation by encasing them in a capillary tube. A clever participant in one of our workshops fashioned an easy tool for inserting them into the tube by wrapping a piece of dental floss around the tube close to one end. The floss acts as a gasket. He then inserted the flossed end of the tube into the end of a plastic pipette. By compressing the pipette bulb gently, he was able to suck the worm into the tube, which immobilizes it. You can use the pipette to create a small bubble of air at either end of the tube, so that the worm cannot escape. The capillary tube containing the worm can then be examined under a dissecting microscope to study the worm's internal structures.

- Hydra – These are hard to keep alive, so do not have them delivered too far in advance. Three days before the hydra arrive, set up brine shrimp eggs in aerated water using the culture media supplied with the kit. When the hydra arrive, carefully move them to a new container and add some of the hatched brine shrimp to the container. Feed small amounts daily. They apparently need to eat constantly, but get overwhelmed by too many shrimp.

- *Corbicula* mussels – Set up an aquarium with about 1" clean sand, filter, bubbler, and light. Add unicellular algae to water every few days, and replace 1/3 of the water in the mussel tank with aged water about once every week. We established algae cultures in aquaria sitting in windows. When we removed some of the water from these aquaria to feed the mussels, we replenished it with aged water to keep the algae cultures going. After the mussels' aquarium is well established, algae will begin to establish within the tank and the algae will not need to be added as often. The mussels are very hardy and can live for months. Dig up them up from the bottom of the aquarium periodically and put on top of the substrate to see which have died (don't burrow back in). To collect *Corbicula*, dig a few inches into the mud in shallow areas of slow moving water (e.g. shallows of rivers). These mussels have brownish-white shells and look like miniature versions of marine clams. Although they can be collected in winter, we collected our in early fall, and kept them going with very little loss until February when we used them. They are invasive and ubiquitous, so you need not worry about returning them to nature at the conclusion of the lab. We preserved ours for student use in subsequent labs. Please do not collect other types of freshwater mussels, as many are threatened species.

- Pond Snails – Place in a shallow bowl with about 2 – 3 inches of aged water containing some algae. Add fresh algae every 3 days or so until algae culture is well established. Do not aerate, but replenish some of the water every week or so. Cover the bowl with a screen (to prevent escapes) and place the bowl under a light to keep the algae growing. These snails can be easily collected from shallow ponds and seeps. We collect ours from a series of rock seeps in a nearby park. They are relatively easy to keep alive, so can be collected well in advance of lab if necessary. In Virginia, they can be collected on warmer days in winter as well as in the warmer months.

- Crayfish – Sort crayfish by size and place 4 – 6 in large aquaria with 2 – 3 inches of water, each with at least one pot shard to hide under. Crayfish can be picked up by grasping them from behind around the thorax between your thumb and forefingers. It may be helpful to distract them by waving a pencil or other object in front of them with one hand while using the other to grasp them. You won't need a bubbler in the tank but if you are keeping them for an extended period of time, you can use one. Feed them crayfish food (cat food or dog food or sinking fish pellets will work as well). They will also eat blackworms readily. Change the water every 3 – 4 days. Crayfish can also be collected from nearby streams.

- Mealworms – Mealworms are easy to maintain. Place wheat bran in a container, and add the mealworms. Feed a slice of apple or potato. Do not add any moisture to the container.

Appendix F

Examples of table design for organizing invertebrate data

One kind table might organize information about one phylum:

Table 1. Characteristics of phylum Arthropoda

Class	Name of representative member	Lives where	Eats what	Locomotion

Another table might compare different phyla:

Table 2. Comparison of invertebrate phyla

Phylum	Examples	Defining traits	tagmata	Terrestrial (T), Aquatic (A) or both (T,A)	carnivorous (C), herbivorous (H) or omnivorous (O)	capable of flight +/-

Of course, the phyla could go on column headings and the topics on row headings.

Appendix G

Phyla included in the invertebrate list in supplemental exercise used at Radford University

Kingdom Animalia

- Phylum Porifera
- Phylum Cnidaria
  - jellys
  - sea anemones and corals
- Phylum Platyhelminthes
  - planaria
  - fluke worms
  - tapeworms
- Phylum Nematoda
- Phylum Annelida
  - polychaetes
  - earthworms
  - leeches
- Phylum Mollusca
  - chitons
  - gastropods
  - bivalves
  - cephalopods
- Phylum Arthropoda
  - arachnids
  - crustaceans
  - millipedes and centipedes
  - insects
- Phylum Echinodermata
- Phylum Chordata
  - tunicates
  - lancets