



Xs and Os:

The Tic-Tac-Toe of Sex Determination

**A Lesson to Supplement the
2001 HHMI Holiday Lectures on Science,
*The Meaning of Sex: Genes and Gender***

XO

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INTRODUCTION

A dizzying array of sex-determination mechanisms exists in the biological world. In some organisms, gender is established at conception; other organisms rely on the environment; and in still others, the genetic control of basic sex constitution can be affected by environmental factors to modify subsequent differentiation.

In this structured-inquiry activity, teams of students evaluate the evidence for how sex is determined in a variety of creatures ranging from a freshwater Amazonian turtle to an invasive North American weed and the common house mouse. Like scientists, they must devise hypotheses to account for the available evidence and share their findings with their peers.

THE “JIGSAW”: A TOOL FOR PEER TEACHING

The activity uses a “jigsaw” format that allows students to research and teach parts of the lesson. The class is divided into student teams (called Expert Groups), and each Expert Group researches one organism. The class then reorganizes into “Home Groups” of students, each of whom studied a different organism. Each student in the Home Group teaches the other students in the group about his or her organism. Themes pertaining to sex determination, evolution, gene regulation, and the nature of science may emerge for discussion.

OBJECTIVES

At the end of this activity, students should be able to

- compare and contrast the wide variety of sex-determination strategies that have evolved in multicellular organisms;
- analyze data and synthesize explanations that reflect the available evidence;
- appreciate human sex-determination mechanisms in context, as one of many such schemes in nature;
- describe the scientific value of model organisms; and
- comprehend one aspect of a subject in detail and teach it to their peers.

CLASSROOM CONNECTIONS

The activity can be integrated into the general biology curriculum or used with AP/honors/IB biology or with a comparative anatomy and physiology course. The activity addresses many [National Science Education Standards](#) in content and teaching.

The lesson can be used alone or in conjunction with the 2001 Holiday Lectures on Science. It would be a good tie-in to the following lecture topics:

- How human gender is determined (first half, Lecture One, Dr. David Page)

- Parthenogenesis in a vertebrate species (first half, Lecture One, Dr. Page)
- The role of *xol-1* and X signal element genes in *C. elegans* (Lecture Two, Dr. Barbara Meyer)
- Evolutionary changes in the human Y chromosome (first half, Lecture Four, Dr. Page)

STUDENTS' PRIOR KNOWLEDGE

Before participating in this activity, students should know

- what a karyotype is and how it is prepared,
- how to distinguish between genes and chromosomes and between autosomes and sex chromosomes,
- how to interpret a simple pedigree, and
- how to use Punnett squares to solve genetics problems involving autosomal or sex-linked characteristics.

**MATERIALS CONTAINED
IN THIS LESSON**

Seven sets of cards
(one set for each organism
includes one Critter Card,
one Karyotype Card, and
three Observation Cards)



One overhead transparency
master: *Template for Xs and
Os: the Tic-Tac-Toe of Sex
Determination*



One overhead transparency
master: *Expectations for
Jigsaw Lessons*



A Teacher Reference Chart

MATERIALS TO SUPPLY

Student journals



Baskets or other containers
to hold cards



Classroom map
(overhead or butcher paper)
showing meeting locations
for Expert Groups (optional)

DIRECTIONS FOR DOING THE ACTIVITY

This lesson was designed for a class of 35 students, using seven Expert Groups of five. **If you do not have 35 students in your class (or if you have a class with students of varying ability), several options for doing the activity are given in [Form Expert Groups](#).**

Here are the necessary steps (the time allocations assume seven Expert Groups):

- Explain the jigsaw. Communicate your overall expectations for the lesson by displaying the overhead transparency [Expectations for Jigsaw Lessons](#). (5 minutes)
- **Engage** students with thought-provoking questions. (20 minutes)
- **Form Expert Groups** for the group researching phase. (20 minutes)
- **Reorganize** the class into Home Groups for the group teaching phase, followed by discussion and processing (70–80 minutes).
- **Assess** students' knowledge. (time will vary; can be completed in or out of class)

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Expectations for Jigsaw Lessons

As a member of your Expert Group:

FOCUS on your task. Assist the other Experts in figuring out what you have to do.

ACHIEVE understanding. Take notes on the Expert Group cards. Be able to explain them in your own words.

RECOGNIZE that *your* work will be important to others.

As a member of your Home Group:

Take turns teaching. When others are teaching, pay close attention to each of the members in your Home Group.

When it is your turn to teach, share your information verbally—do not just exchange journals. Show enthusiasm!

Make sure that the other members of your Home Group understand you.

Engage Students

1. Ask students the following questions (brackets < > denote student responses):
 - When you were born, after the doctor and your parents determined that you were healthy, what is the *next* question your parents probably asked? <“Is it a boy or a girl?”>
 - How would the doctor know? <external genitalia>
 - Before a person is born, can one tell by looking what the sex of a fetus is? of an embryo? of a zygote?
 - How and when is sex determined, not just in humans but also in other mammals, other animals, or even in plants?
2. Have students write in their journals the following task statement for the jigsaw: *Let’s discover how sex is determined in a variety of organisms.*
3. Show the overhead transparency, *Template for Xs and Os: The Tic-Tac-Toe of Sex Determination*, and allow time for students to copy it into their journals. Encourage students to spread the table over multiple pages. Pronounce each organism’s common name and scientific name aloud with your students.

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Template for Xs and Os: The Tic-Tac-Toe of Sex Determination

Species of organism	Sex-Related Info. in Critter Card	Sex-Determination Info. in Karyotype Card	Sex-Determination Hypothesis Consistent with ALL Cards, Including Observation Cards
Spoon worm (<i>Bonellia viridis</i>)			
White campion (<i>Silene latifolia</i>)			
Mouse (<i>Mus musculus</i>)			
Fruit fly (<i>Drosophila melanogaster</i>)			
Yellow-spotted river turtle (<i>Podocnemis unifilis</i>)			
Nematode (<i>Caenorhabditis elegans</i>)			
Chicken (<i>Gallus domesticus</i>)			

Form expert groups

- 1**

 - a.** In a class of 35, have students count off from 1 to 7; orchestrate the counting so that a group of students having numbers 1 through 7 sits close to each other. That way, when students reorganize into Home Groups, they can simply return to their original seats.
 - b.** Before students change seats, have all the 1s raise their hands, all the 2s, all the 3s, and so on. These are the Expert Groups. If you have drawn a simple map, post it on the board or on an overhead transparency to show the locations (widely spaced, if possible) around the classroom in which the Expert Groups are to meet.
 - c.** Have one member from each Expert Group come to the materials station in the classroom to pick up the basket (same number as group) with his or her group's cards and bring it to the designated location. You may want each student to receive one card and lead the discussion on that card's information.
- 2**

 - a.** Tell students to read the cards silently and work in the following order: They should examine the Critter Card first, then the Karyotype Card, and finally, the Observation Cards.
 - b.** Have group members analyze and discuss the information in their cards. Your job is to keep time and to serve as a resource person for each group as needed. Listen to the discussions occurring in each group.
 - c.** Remind them to record relevant information (see column titles!) in *their* row of the chart. The final column is the place where they synthesize an explanation for how sex is determined in *their* organism that is consistent with all the information in their cards.
 - d.** It is imperative that every Expert Group member understands

what he or she needs to teach and how to teach it. Expert Group members have a responsibility to help each other before the group disbands. Each Expert Group member is expected to understand and synthesize the information from all cards.

3. Ask a member from each Expert Group to return the group's card basket to the materials table when the group has completed its task.



Teaching tip: You have an opportunity to spot-check the quality of the work of any Expert Group that finishes early. Pick up the journal of any student in the group and use it to question the group about what its members have concluded and how they arrived at their conclusions.

To adjust the activity for different class sizes and classes of varying abilities:

- Use all seven organisms but have fewer students for each Expert Group. For example, in a class of 28 students have four students in each group.
- Choose fewer than seven organisms but maintain an Expert Group of five students.
- Choose three organisms but have duplicate sets of cards (six sets). This set-up allows two expert groups to compare hypotheses.
- Have small Expert Groups stay together and rotate through the seven information stations.
- Have each Home Group member become an expert on two species.
- Have a member of each Expert Group teach in front of the entire class.
- For classes with varying abilities, choose organisms based on level of difficulty:

Easy	Moderate	Difficult
Spoon worm, <i>Bonellia viridis</i> Yellow-spotted river turtle, <i>Podocnemis unifilis</i>	Fruit fly, <i>Drosophila melanogaster</i> Mouse, <i>Mus musculus</i> White campion, <i>Silene latifolia</i>	Chicken, <i>Gallus domesticus</i> Nematode, <i>Caenorhabditis elegans</i>

Reorganize

1. Instruct students to return to their original seats. Point out the groups of students with numbers 1–7. These are Home Groups. In a class of 35, there will be five Home Groups. Be sure students move their seats toward each other and speak clearly so that they can hear what each other has to say.
2. Tell students that Home Group members should take turns teaching about the organisms on which they became experts. As before, your job is to be timekeeper. As a general rule of thumb, each student in the Home Group needs 5–10 minutes for teaching. Resist the temptation to elaborate on or correct information while the students teach. There will be opportunities later to ensure the accuracy of the knowledge.



Teaching tip: A group may be “short” a teacher (because of an odd number of people in the class or due to absence). Borrow a teacher for them from a group that finishes early, or be a “substitute teacher” yourself.



Teaching tip: Borrow a journal from one student in each of the four Home Groups before conducting the discussion (for example, overnight, or between days of the lesson). Reassure these students that their journals will not be “graded.” Review their jigsaw charts for missing or inaccurate information to alert you to particular points to visit in the discussion.

You might also take the opportunity to photocopy a good chart as a student-friendly key for students with visual learning styles who want to *see* as well as listen to a complete set of responses from the jigsaw.

3. Engage the class in a discussion of the content learned. Highlight the similarities among, and differences between, sex-determination strategies. Questions for discussion should include the following:

- In which organism(s) does the presence or absence of a gene on a particular chromosome govern gender?
- In which organism(s) is sex determined by the ratio between gene products of the X chromosome(s) and gene products of autosomes?
- In which organism(s) does an environmental factor determine sex?

Follow every student response with, “How do you know?” See the “Teacher Reference Chart” for other discussion ideas.

4. Allow students to debrief the format of the lesson, particularly if this was their first jigsaw. Give them an opportunity to discuss how well the Expert and Home Groups functioned—the kinds of interactions that occurred (positive and negative), whether the members felt they were being listened to, and how successful they were in accomplishing the task.

Assessment

Looking at a sample journal from each Home Group is one kind of formative assessment. For summative assessment, you could do the following:

- Ask the Home Groups to summarize what they learned in writing.
- Ask the Home Groups to orally summarize what they learned.
- Administer a short quiz that the members of each Home Group take together or that each student takes independently, with or without journals. See sample questions for assessment that follow.
- Organize the class into six Expert Groups at the outset instead of seven in order to save one set of cards. Then, after the jigsaw, give each student the seventh set of cards to analyze.

SAMPLE QUESTIONS FOR ASSESSMENT

1. Categorize each of the organisms in the activity by the trigger for their sex determination (environment, X:A ratio, or chromosome with sex-specific gene).
2. In which organisms were male and female karyotypes identical? What conclusion might be drawn about their common sex-determination trigger?
3. Suggest a mechanism that might account for temperature-dependent sex determination? Hint: the operation of which organic molecules is greatly influenced by temperature?
4. Using Venn diagrams, clustering, or another kind of graphic organizer, illustrate the evolutionary relationships between each of the seven organisms in this activity. Include detail to the level of Order when possible.
5. In both *C. elegans* and *D. melanogaster*, the X:A ratio determines sex. Compare and contrast the details of sex determination in

these two species. Try to give at least two similarities and two differences.

6. What conclusions about avian sex determination might be drawn from the discovery in the future of a ZO rooster?
7. What evidence supports the idea that the Y chromosome of *Drosophila* does not confer maleness?
8. What approach or strategy could biologists use to identify the male-inducing chemical in spoon-worms?
9. How might molecular biology techniques be used to confirm that certain genes on the Y chromosome of *S. latifolia* block carpel development?
10. What conclusion about avian sex determination might be drawn from the 1933 observation of a diploid ZZW male bird? What is wrong with basing conclusions on single observations? Should a single observation made today (and not in 1933) carry more weight? Explain.
11. Propose a follow-up experiment to one of the Observation Cards for one of the organisms in the activity. Be sure to explain what should be done and why.
12. Predict what the karyotype of the spoon worm (*Bonellia viridis*) might look like.
13. How do organisms in which males and females have unequal numbers of a sex chromosome compensate for an imbalance in gene dosage (for example, female mice having twice the gene product from the X chromosome than male mice)? In what other organisms in this activity might some form of “dosage compensation” be expected?
14. If you could have a six-week internship in a research lab learning about the genetics of one of these seven organisms in greater detail, which organism would you want to study, and why?

Applications of National Science Education Standards (National Academy of Sciences, 1996)

CONTENT STANDARDS

- A. As a result of activities in grades 9–12, all students should develop abilities necessary to do, and understandings about, scientific inquiry.
- Formulate and revise scientific explanations and models using logic and evidence,
 - Recognize and analyze alternative explanations and models,
 - Communicate and defend a scientific argument.
- C. As a result of activities in grades 9–12, all students should develop understanding of
- The cell
 - Molecular basis of heredity
 - Biological evolution
 - Behavior of organisms
- G. As a result of activities in grades 9–12, all students should develop understanding of
- Nature of scientific knowledge
 - Historical perspectives

TEACHING STANDARDS

- B. Teachers of science guide and facilitate learning. In doing this, teachers
- Focus and support inquiries while interacting with students
 - Orchestrate discourse among students about scientific ideas
 - Challenge students to accept and share responsibility for their own learning.

- C.** Teachers of science engage in ongoing assessment of their teaching and of student learning. In doing this, teachers
- Use multiple methods and systematically gather data about student understanding and ability.
- E.** Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning. In doing this, teachers
- Nurture collaboration among students
 - Structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse.

Credits

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Image and Figure Credits

GENERAL

The American Journal of Botany

SPOON WORM

Dr. Rene Hessling

CHICKEN

Handbook of Genetics-Vertebrates of Genetic Interest. Vol. 4 ed. R.C. King. New York: Plenum Press, 1975.

MOUSE

The Jackson Laboratory, Mouse Genome Informatics

Ellen C. Akeson and Muriel T. Davisson, Ph.D.

McLaren, A. 1991. The making of male mice. *Nature* 351: 96–121.

TURTLE

Turtles of the World, copyright Expert Center for Taxonomic Identification Biodiversity Center, 1998. www.eti.uva.nl

Cytogenics, Medical and Scientific Publishers

Society of the Study of Amphibians and Reptiles

WHITE CAMPION

Wisconsin State Herbarium and Robert W. Freckman, University of Wisconsin, Stevens Point

Negrutiu, I., Vyskot, B., Barbacar, N., Georgiev, S., and Moneger, F. 2001. Dioecious plants: a key to the early events of sex chromosome evolution. *Plant Physiol.* 127: 1418-1424. Copyright American Society of Plant Biologists. Reprinted with permission.

NEMATODE

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FRUIT FLY

Klug, W.S., and Cummings, M.R. *Concepts of Genetics*. 6th ed. (c)2000. Electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey

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