

# Toothpick Fish

## A Middle School Activity for Teaching Genetics and Environmental Science

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An earlier version of this document can be downloaded as part of  
*The Genetics Education Guide* at:

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# Toothpick Fish

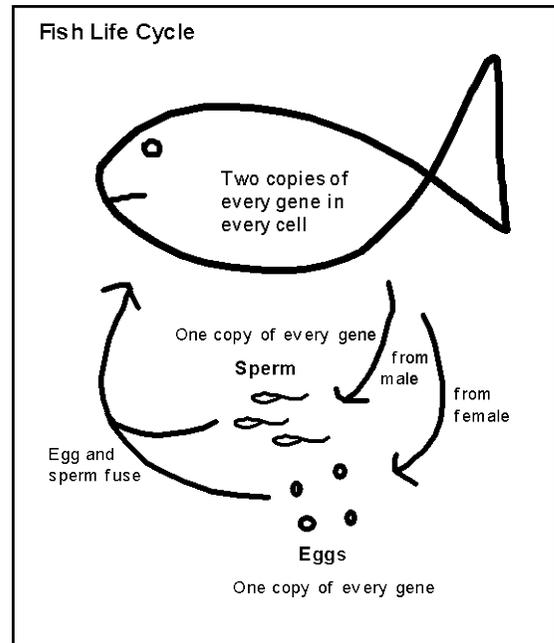
## Student Instructions and Worksheet

### Purpose

We are going to experiment with genes and environment for a population of “toothpick” fish. You will learn about the relationships between many different aspects of fish life: genes, traits, variation, survival, and reproduction. The activity here is a simulation, but it models the way fish and other organisms live in nature.

### Materials (for each pair)

- 1 “gene pool” container (e.g. a petri dish)
- 8 green toothpicks
- 8 red toothpicks
- 8 yellow toothpicks



### Introduction

The colored toothpicks represent three different forms of a gene (green, red, and yellow) that controls one fish trait: skin color. The table below tells you which forms (alleles) of the gene are dominant, which are recessive, and which are equal (or co-dominant).

The green gene (G) is...	<ul style="list-style-type: none"> <li>• dominant to all other color genes</li> </ul>
The red gene (R) is...	<ul style="list-style-type: none"> <li>• recessive to green</li> <li>• equal (“co-dominant”) to yellow *</li> </ul>
The yellow gene (Y) is...	<ul style="list-style-type: none"> <li>• recessive to green</li> <li>• equal (“co-dominant”) to red *</li> </ul>

\* Combining red and yellow genes results in a fish with orange skin color.

REMEMBER: EACH TOOTHPICK REPRESENTS A GENE, NOT A FISH.

### Directions:

1. Count your toothpicks to make sure you have 8 of each color for a total of 24 toothpicks.

2. Figure out which gene combinations give rise to which fish colors and fill in the answers on the table on the next page.

Fish Color	Gene combinations
Green	e.g. GG, . . .
Red	
Yellow	
Orange	

Based on the answers you gave in the table above, answer the questions below. (You may use Punnett Squares if you wish.)

- a. Can two red fish mate and have green offspring? Why or why not?
  
- b. Can two orange fish mate and have red offspring? Why or why not?
  
- c. Can two green fish mate and have orange offspring? Why or why not?
  
3. Make a *first generation* of fish. To do this, pull out genes (toothpicks) in pairs without looking and set them aside carefully so that they stay in pairs. This simulates the way offspring are formed by sperm from the male fish combining randomly with eggs from the female fish. Once you have drawn your twelve pairs, record the results in Table A. An example fish in the first generation is given in Table A in the shaded boxes (do not include this fish in your calculations).
  
4. Count the numbers of each color of fish offspring and record the numbers in Table B where it says *first generation*.

The stream where the fish live is very green and lush with lots of vegetation and algae covering the streambed and banks. The green fish are very well camouflaged from predators in this environment and the red and orange fish fairly well also. However, none of the yellow fish survive or reproduce because predators can easily spot them in the green algae environment. **If you have any yellow fish (fish in which both toothpicks are yellow), set those toothpicks aside.**

5. Put all the genes you have left back in the gene pool (**remember, you have set aside any yellow fish**). Draw a *second generation* of fish, again without looking. Record your gene pairs in Table A. Total up the fish of each color and record the numbers in the *second generation* row in Table B. Set aside yellow fish and return surviving fish to the cup.
6. The well-camouflaged fish live longer and have more offspring, so their numbers are increasing. Draw toothpicks to make a *third generation* of fish. Record your data in Table A and then write in the total numbers of each color in the *third generation* row of Table B. Now return survivors to the gene pool (be sure to set aside any genes from yellow offspring).

**STOP HERE. DO NOT PROCEED TO STEP 7. DISCUSS THE FOLLOWING THREE QUESTIONS WITH YOUR PARTNER AND WAIT FOR FURTHER INSTRUCTIONS.**

- a. Have all the yellow genes disappeared?
  - b. Has the population size changed? In what way? Would you expect this to occur in the wild?
  - c. How does the population in the third generation compare to the population in the earlier generations?
7. Draw more pairs of genes to make a *fourth generation* of fish. Record the data in Tables A and B. Do not remove yellow fish.

**STOP! An environmental disaster occurs.** Factory waste harmful to algae is dumped into the stream, killing much of the algae very rapidly. The remaining rocks and sand are good camouflage for the yellow, red, and orange fish. Now the green fish are easily spotted by predators and can't survive or reproduce.

8. Because green fish don't survive, set them aside. Now record the *surviving* offspring (all but the green) in the last row of Table B (fourth generation survivors row). Contribute your final data on the class tally on the overhead projector. Your instructor will total the data for the entire class.

After examining the data for the entire class, discuss the following questions with your partner.

- a. Has the population changed compared to earlier generations? How?
- b. Have any genes disappeared entirely?
- c. Yellow genes are recessive to green; green genes are dominant to both red and yellow. Which color of genes disappeared faster when the environment was hostile to them? Why?

**For discussion:**

Hatchery fish populations often have less genetic biodiversity than wild fish populations. How might lowered biodiversity affect a fish population's ability to adapt to environmental disasters such as the pollution disaster described in this simulation?

If the fish from a particular stream have become genetically adapted to their home stream over many generations, what might happen if their fertilized eggs are used to "restock" a different stream that has become depleted of fish?

Can you think of any examples from the real world where lowered genetic diversity is impacting a species' ability to survive?

# Toothpick Fish

# Teacher's Notes

## Summary

In Toothpick Fish, a population genetics simulation, students observe and record the genotypic and phenotypic make-up of a fish population, which change in response to environmental conditions and an event that changes these conditions. Events similar to the catastrophic event in this activity—vegetation dying because of pollution—could happen in real streams in the real world. Toothpick

Toothpick Fish provides a good synthesis of basic genetic concepts with a focus on the environment and natural selection. The changing frequencies of genes in the population in response to the environment is a dramatic demonstration of natural selection at work and provides a good introduction to this major mechanism of evolution. As well as being suitable as an everyday classroom activity, Toothpick Fish can also be used as a summative assessment following a unit on genetics.

## Student Background

This activity is designed for middle school students. Students should have been exposed to basic genetic concepts before beginning this activity. They will need to know, for example, that genes occur in pairs and that offspring inherit one copy of each gene from each parent and that which copy of each parent's gene is inherited is random. Students will also need a clear understanding of dominant and recessive genes, and need sufficient knowledge of how to use Punnett Squares or another method to predict offspring genotypes based on parental genotypes. The activity also provides an example of codominant or incomplete dominant inheritance and could serve as students' first exposure to this form of inheritance. Students do not need previous exposure to molecular genetics concepts, such as the structure of DNA or the genetic code.

## One or Two Day Activity?

Whether your students can complete the activity in one or two days depends on their preparation in genetics before beginning the activity. If many students are on shaky ground predicting offspring genotypes, we advise taking two days and integrating a review of basic genetics with the activity.

## List of Overhead Masters

- Fish Life Cycle
- Introductory Tables: table showing rules of fish skin color inheritance and table for students to fill out in question 2
- Table C. Fish surviving the pollution disaster: pooled data.

## Procedure

Hand out the student instructions and worksheet entitled "Toothpick Fish." Briefly review the reproductive cycle of the fish as shown on the first page of the instructions. An overhead master with a larger version of the life cycle picture is included in this packet.

Hand out the gene pool containers (cups or plastic petri dishes with covers) and colored toothpicks (pre-count 8 of each of the green, red, and yellow, for a total in each container of 24). Each toothpick's color represents the information carried by that gene, that is, either green, red, or yellow skin. Drawing two toothpicks at random from the dish represents fusion of an egg and a sperm to form a new fish, with two copies of the skin color gene. **Remind students that each toothpick represents a gene and not a fish.**

Go over the rules of fish skin color inheritance with the class (e.g. “the green gene is represented by the letter G and is dominant to all other color genes”). The rules of inheritance are listed in the table on the first page of the student handout. Have students work in pairs and fill out the table in question 2 and then answer questions 2a-2c on their worksheet. An overhead master that contains the rules of inheritance table and the question 2 table is included in this packet. To fill out the table, students should lay out before them on their desks the gene pairs that produce a green fish (GG, GR, GY), a red fish (RR), an orange fish (RY), and a yellow fish (YY). When they have the population's dominant/recessive gene pattern in hand, have them work through the instructions that follow.

In #3 and #4 of the instructions, students draw pairs of toothpicks and tally the resulting fish genotypes and colors in **Tables A and B**. You can compile the class results on an overhead transparency (not provided) or the blackboard and ask a few questions about them:

- Why are there so many green fish?
- Why are there so few red, orange, and yellow fish?

In instruction #4, the environment comes into play. Yellow fish are poorly camouflaged and get eaten before they can spawn. Read from #4 out loud to the class **“If you have any yellow fish—fish in which both toothpicks are yellow—, set those toothpicks aside.”** Emphasize that it is important to eliminate the yellow fish before continuing to draw future generations.

Have students move on to instructions #5 and #6 and draw two more generations of fish for a total of three generations. The genotypes and colors of fish offspring are tallied and recorded in **Tables A and B**. Students should not continue onto #7. After students have drawn three generations, discarding all resulting yellow fish, you can again tally the class results.

The yellow gene is clearly not increasing the yellow fish's chance of surviving. Consider these questions:

- Have *all* the yellow genes disappeared? How long do you think it would take before they did?  
*No, there are still some yellow genes present. It would be some time before the yellow genes all disappeared, because they are so often masked by other, dominant genes.*
- Has the population size changed? In what way? Would you expect this to occur in the wild?

*Yes, the population size of the student gene pools has probably gotten slightly smaller. Whenever students remove a yellow fish, the gene pool shrinks by 2 genes. No, we would not expect this to occur in the wild because there are a vast excess of eggs laid and fish juveniles hatched compared to how many survive to adulthood no matter what their color. This, then, is an aspect of the simulation that does not reflect real life.*

- How does the population in the third generation compare to the population in the earlier generations?

*It will probably have fewer yellow genes. An increase in green genes may or may not be apparent after only a few generations. If the fish species in this activity were one that spawned more than once per lifetime, then the green fish, surviving longer than the others, would spawn more often, adding more genes to the pool. However, in this simulation, we have not allowed green fish to contribute more genes to the pool. Have students consider the limitations of the simulation and suggest ways to modify it to account for this complexity. One imperfect solution would be to have students add additional genes from green fish to the gene pool after each generation. In some fish species, such as the Pacific Salmon, fish spawn only once per lifetime, so the toothpick fish activity mimics more closely the life cycle of this species.*

Have students move on to #7 and draw a fourth generation of fish and record their data in **Tables A and B**. But this time, they do not remove the yellow fish because....

**“An environmental disaster occurs. Factory waste harmful to algae is dumped into the stream, killing much of the algae very rapidly. The remaining rocks and sand are good camouflage for the yellow, red, and orange fish. Now the green fish are easily spotted by predators and can’t survive or reproduce.”**

Instruction #8 tells students to set aside their green fish and record the remaining fish in **Table B** on the Fourth Generation Survivors line.

Use the provided overhead, **“Table C. Fish surviving the pollution disaster: pooled data,”** to tally up the data from all the student pairs. Have students examine the data from the entire class and consider questions 8a-8c.

- Has the population changed compared to earlier generations? How?  
*Yes. It is now significantly smaller and some genes have disappeared entirely.*
- Have any genes disappeared entirely?  
*Yes. The green genes have completely disappeared.*
- Yellow genes are recessive to green; green genes are dominant to both red and yellow. Which color of genes disappeared faster when the environment was hostile to them? Why?

*The green genes all disappeared immediately when they were selected against by the sandy colored stream bed conditions. This is in contrast to the slow decline in yellow genes that was observed under conditions when the stream bed was green and yellow fish were selected against. Green genes disappeared immediately because they are dominant and always expressed. Any fish having a green gene is green in color. The yellow genes declined slowly because they are recessive and masked by the presence of a gene of another color (green or red). The take home message is that dominant genes can be eliminated quickly from a population by a new selective pressure. Recessive genes decline slowly because they are hidden or masked.*

### **Extra Questions (not on student sheets)**

- Real populations change much more slowly than these toothpick fish. Why?  
*Changes in the environment are usually much more gradual than in the fish simulation, for example, the coming of an Ice Age or the encroachment of trees into an open field. Also, real populations are usually large, containing hundreds or thousands of individuals. In a large population of toothpick fish, it is unlikely that the green individuals would so quickly outnumber the others, or that all green fish would be eliminated in one generation. However, occasionally there is a rapid change in the environment (often caused by humans) that can have a dramatic effect, especially in small populations, as in the pollution-induced disappearance of green algae and vegetation in the fish activity.*

Students generally understand the fish simulation well enough to answer some "What If" questions, extending the concepts from the activity.

- *What if* each of you had started with only one green gene among your fish? How would the population have been different?
- *What if* the orange fish had been best camouflaged, so that a few green fish were eaten each generation?

Let students propose their own what if questions too. Students are often eager to test some of their answers. If time allows, the Toothpick Fish problems can be done again with new conditions.

- If brown eyes are dominant, why don't we all have brown eyes?  
*Perhaps brown eyes are not an advantage for survival. Or, there may be few brown-eye genes in the human gene pool, compared to the number of blue-eye genes. (In fact, eye color inheritance is not as simple as this. Eye color is a polygenic trait, a trait that involves multiple pairs of genes, rather than one pair. However, for purposes of this discussion, it is a relevant example).*
- How does the variety in a gene pool impact adaptability?

*Imagine Two Populations:*

Population A

*Has a gene pool that contains several different color genes, giving rise to a multi-colored population (e.g. the toothpick fish population).*

Population B

*Has a gene pool that contains one kind of gene that determines color, giving rise to a single-colored population.*

*In this example, population A has a variable gene pool, and population B has a homogeneous gene pool. Each of these situations has advantages and disadvantages. In a stable environment, a homogeneous population can maintain its numbers from generation to generation, with few members lost, since all its members are equally well adapted to the environment. This type of population is, however, vulnerable in the event of rapid environmental changes. In a variable population, only a few members of each generation are highly adapted to any given environment. But should the environment change, it's likely that a few other members of the variable population will have the characteristics that aid survival in the new conditions.*

**“Discussion Questions” (on student sheets)**

Three discussion questions relating the toothpick fish activity to real world scenarios, such as fish hatchery practices, are included on the student sheets. You may find these questions may be very challenging for the middle school level. We routinely use them when we do this activity in our professional development sessions for teachers. You may or may not want to tackle them with your class.

- Hatchery fish populations often have less genetic biodiversity than wild fish populations. How might lowered biodiversity affect a fish population’s ability to adapt to environmental disasters such as the pollution disaster described in this simulation?

*The fish population would have a poor capability for adapting to new conditions. Consider the surviving toothpick fish population after the pollution killed the stream vegetation. The population has very low genetic diversity (no green genes and reduced red genes). What will happen to the population if the green stream vegetation grows back? The many yellow fish in the population will be easy marks for their predators and will be unable to adapt to the new stream color due to the lack of green genes in the gene pool.*

*After learning these concepts thoroughly, students often believe that a hatchery would “know better” than to create fish populations with low genetic diversity. However, this is not the case. Hatchery fish populations routinely have extremely low genetic diversity despite scientific knowledge that this is detrimental to a population’s fitness. There is a long history of the fishery industry and the scientific community not accepting each other’s “wisdom.”*

- If the fish from a particular stream have become genetically adapted to their home stream over many generations, what might happen if their fertilized eggs are used to “restock” a different stream that has become depleted of fish? (Restocking one stream with eggs from another is a common hatchery practice.)

*The fish would be poorly adapted to the new stream. Consider this possible situation: fish that had to jump up steep waterfalls to get to their spawning grounds might have become, over many generations, very, very large and powerful. Smaller, weaker fish would never make it up the falls and so would not get to spawn or would have to spawn in less favorable areas. So, over time, the fish population had become very large because genes controlling large size had been selected for. Now imagine that the eggs of these fish are transplanted into a new environment--a narrow and shallow stream with narrow rocky crevasses through which fish must leap as they move to their spawning grounds. Many of these fish would get stuck or beached as they try to reach the spawning grounds and the fishery restocking would be a disaster, with few eggs being laid and even fewer reaching maturity.*

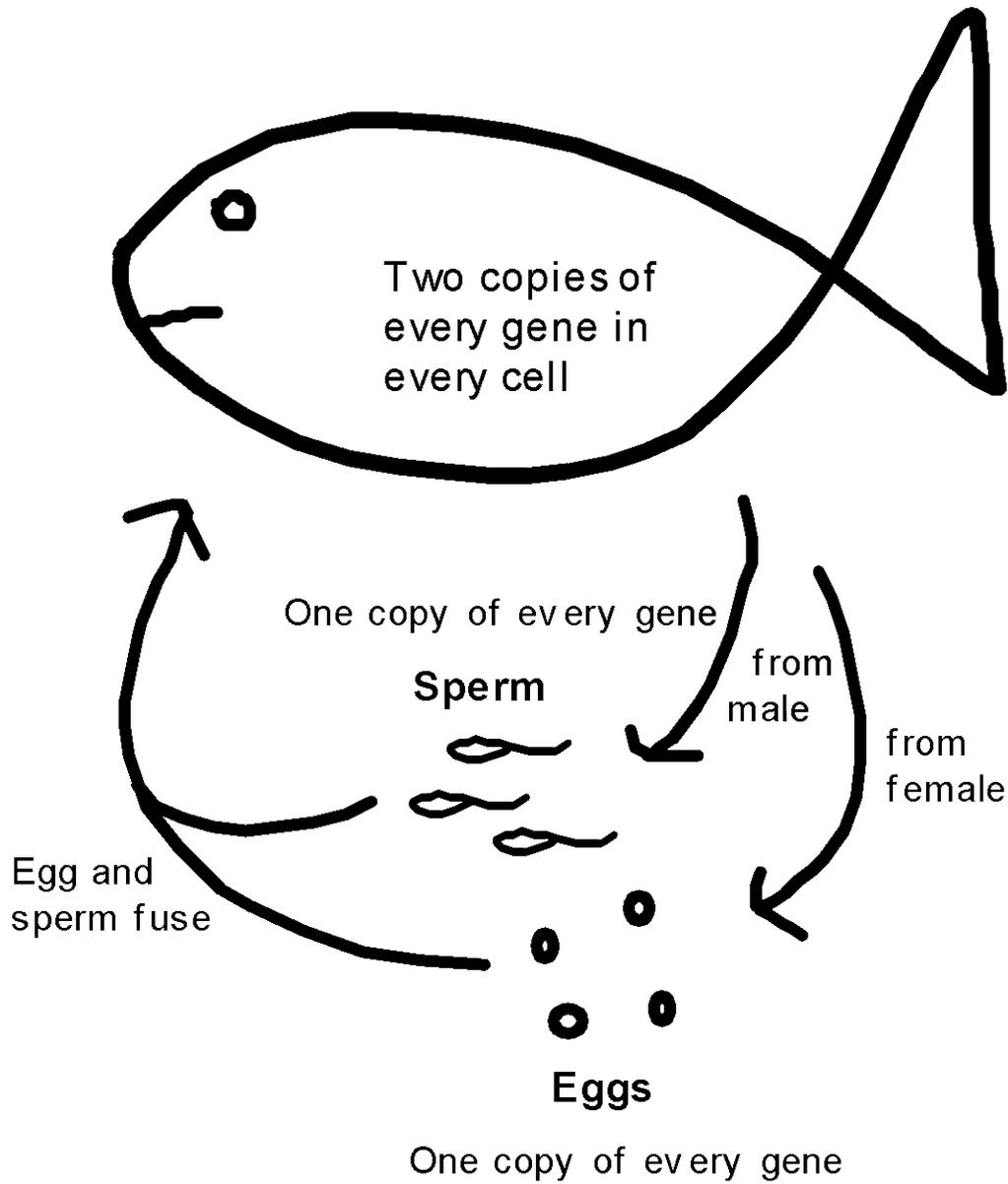
- Can you think of any examples from the real world where lowered genetic diversity is impacting a species' ability to survive?

*There are many examples. Here are two. Students may be familiar with others.*

**Florida Panther.** *Breeding stock from a related panther/cougar species from Texas has been used to shore up the Florida Panther population, victim of a narrow gene pool among other catastrophes (severely decreased habitat due to increasing development in Florida).*

**Cheetah.** *Cheetahs are reportedly having a difficult time surviving due to their limited genetic diversity. There is some controversy about this explanation, however. Another view is that the cheetah is so highly adapted, with its unique body structure designed for ultra high speeds (remember, the cheetah is the fastest animal on earth), that much diversity has been selected out of the population. In this view, cheetahs are declining not due to low genetic diversity but because of their increased hunting by humans, loss of habitat, etc.*

# Fish Life Cycle



Overhead Master

# Toothpick Fish

# Table A

**Table A. Gene Pairs and Resulting Fish Colors in Generations 1 – 4**

	First Gene/Second Gene				Resulting Fish Color			
	- - - G E N E R A T I O N - - -							
Offspring	1st	2nd	3rd	4th	1st	2nd	3rd	4th
example	G/R				green			
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								

## Toothpick Fish

## Table B

**Table B. Offspring Color for Toothpick Fish Generations**

Environment	Generation	Green	Red	Orange	Yellow
There is lots of green seaweed growing everywhere.	First				
	Second				
	Third				
The seaweed all dies and leaves bare rocks and sand.	Fourth				
	Fourth (survivors)				

