ONLINE INQUIRY & INVESTIGATION

USING MANIPULATIVES To Teach Basic Mendelian Genetics Concepts

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Due to its abstract nature, genetics is one of most challenging topics for introductory biology students (Lewis & Wood-Robinson, 2000; Bahar, et al., 1999), yet it is one of the most important and socially relevant topics in the contemporary field of biology. Many biology educators have offered creative lesson plans to enhance students' conceptual understanding of this difficult topic (Ruch, 1998; Haws & Bauer, 2001; Schanker, 1999; Omoto, 1998). A number of these contributions have in common the idea that turning abstract concepts into concrete experiences can greatly aid student mastery of the content. Many use some form of "manipulative"—a set of objects or materials that students actively manipulate with their hands in order to model or represent the biological topic under study. Using manipulatives helps students activate their visual and tactile senses in order to better engage their minds; thus abstract details about structures and terms can become concrete, colorful, and meaningful.

Using LEGOs® as the main manipulative material, this activity provides a concrete foundation and analogy for students to use as they build their understanding of key Mendelian genetics concepts such as phenotype, genotype, heterozygous, homozygous, recessive alleles, and dominant alleles. It is inductive by design: Students engage in a structured experience before general principles, concepts, and specific terms are discussed or identified. Some studies have shown that this inductive or learning cycle method of instruction can be effective for deeper understanding and retention of concepts (Abraham, 1989; Bay et al., 1990). This activity should be carried out after a basic introduction to the relationship between genes and chromosomes has been presented. The activity typically takes approximately 50-60 minutes to carry out.

Figure 1.
Materials: two distinct LEGO® shapes, representing alleles.

Materials (Per Student Team of Two)

- Two shapes of small, distinct LEGOs® to represent alleles[1] (see Figure 1). Fifteen pieces of one shape and 15 of another shape are needed. Other possible substitutes for the LEGOs® could be wooden blocks, dry beans, paper clips, or any small item that can fit into a small container.
- Two distinctly-colored paper coffee cups (such as red and blue) with lids (for securing LEGOs® inside) to represent an organism and its two color phenotypes. Six of each differently colored coffee cups are needed. Other possible substitutes for paper coffee cups could be film vials, painted plastic organism containers from biological supply companies, plastic Easter eggs, etc.
- 8.5 X 11.5 inch Punnett square Template handout (see Master 1)
- A container to hold extra LEGOs® of both shapes (see Figure 2)

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[1]This exercise uses black "2 cm x 2 cm LEGO® square **bricks**" (Item #3495) and "2 cm x 2 cm steep slope **roof tiles**" (Item #3453). LEGO®, PO Box 1310, Enfield, CT 06083; www.lego.com.

Instructor Pre-Activity Preparation

1. Determine the number of student teams.
2. Prepare and label a set of three coffee cups with lids per team (see Figure 3). For the sake of clarity, I will use the colors red and blue.

   Put two LEGO® bricks in a blue coffee cup and label it "A."

   Put one LEGO® brick and one LEGO® roof tile in a blue coffee cup and label it "B."

   Put two LEGO® roof tiles in a red coffee cup and label it "C."
3. Prepare a LEGO® "Extras" container for each team and place 12 bricks and 12 roof tiles in it.
4. Prepare to provide eight additional empty and unlabeled coffee cups, four red and four blue, to each team.
5. On a poster-size paper, draw a filled-out Punnett square showing a monohybrid homozygous cross (see Procedure, Part B, #1 for specifics). Draw the LEGO® shapes with a black marker.
6. Copy one Punnett square Template per team (see Master 1).
7. Copy the Punnett square Analysis handout; two for each student (see Master 2).

Learning Outcomes

After completing this activity, students will be able to:

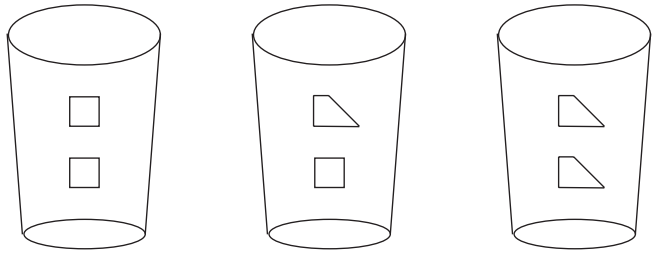
- Associate genes and genotype with traits and phenotype.
- Use Punnett square analysis to predict the genotype and phenotype of offspring.
- Define and correctly apply the following genetic terms: allele, genotype, phenotype, heterozygous/heterozygote, homozygous/homozygote, dominant allele/dominance, recessive allele/recessiveness.

Overview of Activity

1. Instructor previews the learning outcomes.
2. Students become familiar with the manipulatives and the activity's analogy (Part A).
3. Students use materials to perform "virtual matings" using Punnett square Template (Part B).
4. Instructor introduces the key genetics terminology (Part C).
5. Students review and reflect (Part D).

Figure 2.
Materials: a container with extra LEGOs®; two distinct LEGO® shapes that represent alleles; one colored coffee cup with lid representing an organism/phenotype.

Figure 3.
A representation of the coffee cups and their contents.



Coffee Cup A
Blue
2 Brick LEGOs®

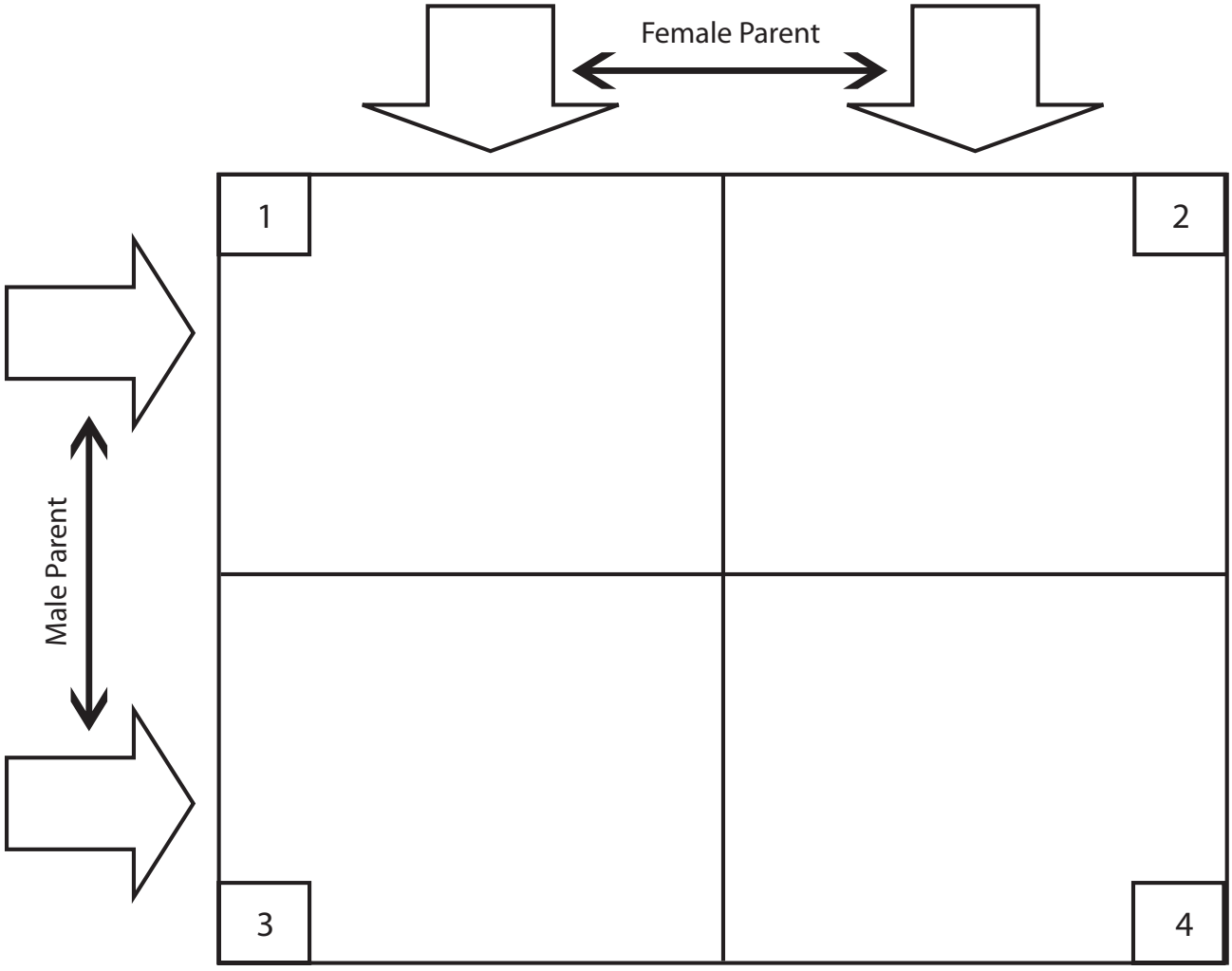
Coffee Cup B
Blue
1 Roof Tile LEGO®
1 Brick LEGO®

Coffee Cup C
Red
2 Roof Tile
LEGOs®

Procedure: Part A

1. Review the relationship between genes and chromosomes.
2. Give each student team:
   - The set of three coffee cups (A, B, and C) with their unique LEGO® combinations (see Instructor Pre-Activity Preparation #2).
   - The LEGO® Extras container (see Instructor Preparation # 3).
   - The stack of additional red and blue containers (see Instructor Preparation # 4).
3. Observations
   - Tell the class that every team receives the same material for this activity.
   - Ask them to observe the coffee cups and their contents.
   - Ask students to share their observations.
   - Record their observations by drawing a diagram similar to Figure 3. Place this in a location where all students can readily and clearly see it for the rest of the activity. Ask students to

Master One: Punnett square Template



(Each numbered box represents a potential offspring)

record the diagram in their notes.

4. Analogy to Genetics
   - Explain the purpose of the materials and activity: The coffee cups and LEGOs® provide a concrete analogy and model to understand basic genetic principles and key genetic terminology.
   - Tell the students the analogy and write it on the board.

     coffee cup = organism

     coffee cup's color = trait

     LEGOs® = genes that determine the color trait
   - Ask students why they think each organism has two genes for determining color. (*Answer: One gene was received from each parent leading to two copies in an organism/coffee cup.*) Relate this to the idea of paired chromosomes.
   - Ask students to focus their attention on Coffee Cup B (the one with two different LEGO® shapes in it). Use this as a reference to explain the concept of *allele.*

     Write on the board the definition of allele: genes for a trait that come in different versions.

     gene = LEGO®; alleles = brick and roof tile variants

     Gene is ice cream flavor; alleles are strawberry and chocolate varieties.

Procedure: Part B

1. To help students understand how the inheritance and interplay of alleles affect the color of offspring, they will "mate" Coffee Cup A (the one with two LEGO® bricks inside) with Coffee Cup C (the one with two LEGO® roof tiles inside). Advise students that an organism's gender is not important for this

and the other matings that will follow.

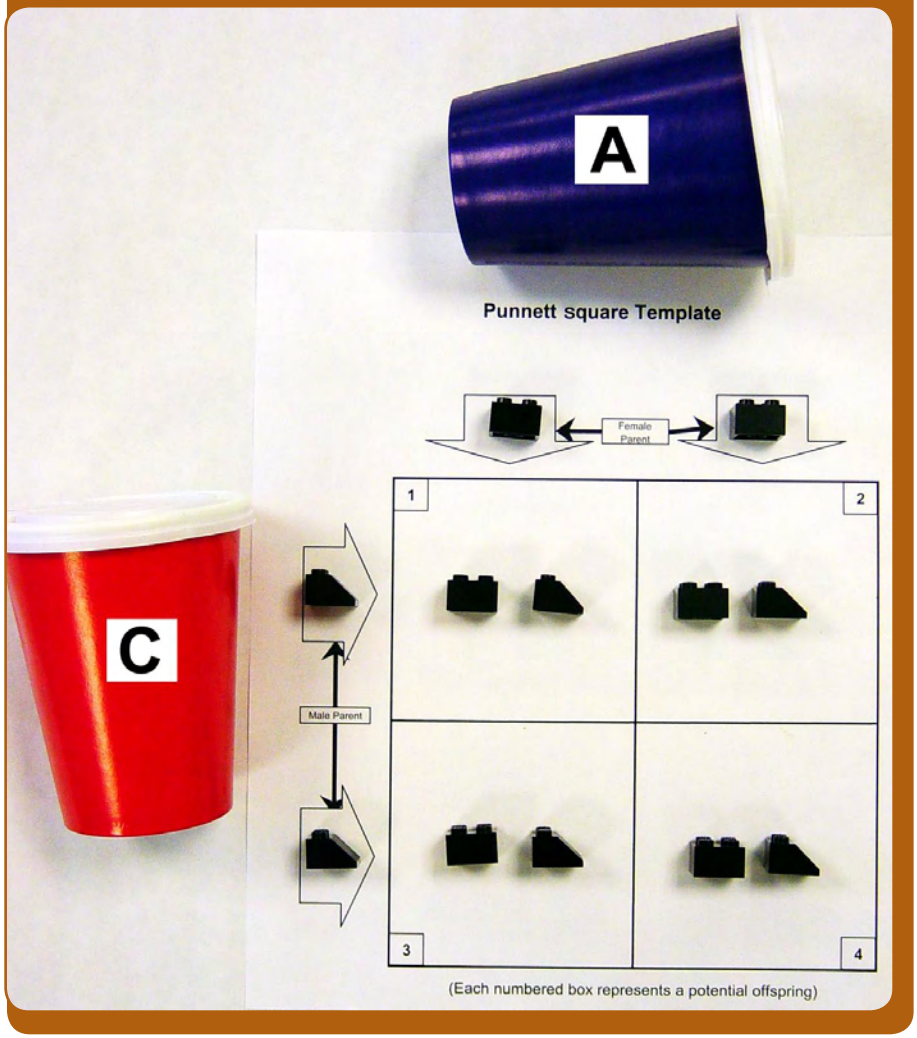
2. Modeling the use of the Punnett square Template:
   - Distribute the Punnett square Template (Master 1) to each team and explain that it is a tool to understand how genes are passed from parents to offspring by identifying all possible allelic combinations in offspring.
   - Students should open the two coffee cups (A and C) they will "mate" to clearly see their contents.
   - Place Coffee Cup A next to and above the female parent box on the Punnett square Template. Place Coffee Cup C next to and beside the male parent box on the Punnett square Template (see Figure 4 for next four steps).
   - Tell students to take two bricks from the Extras container and place them in the big arrows next to the female parent box. This represents Coffee Cup A's genes. **Important Reminder:** Do not remove LEGOs® from the coffee cups! This is so that mix-ups will not occur.
   - Tell students to take two roof tiles from the Extras container and place them in the big arrows next to the male parent box. This represents Coffee Cup C's genes.
   - Using the pre-made poster (see Instructor Preactivity Preparation #5), model how to take LEGOs® from the Extras container and distribute them within the Punnett square to show that each parent donates only one of two alleles/LEGOs® to any one offspring. Explain how this shows Mendel's Law of Segregation, if desired. (Alleles separate during gamete formation, and randomly unite at fertilization.)
   - Discuss the following analysis questions with the entire group:

     How many allele/Lego combinations are possible? (*Answer: 1*)

     What is the probability (chance) of getting each combination? (*Answer: 4/4 or 100%*)

     What color(s) will the offspring be? (*Answer: All blue*)

Figure 4.
LEGOs® distributed in Punnett square Template.



   - To make the LEGO®/Coffee Cup connection even more visually concrete, ask students to take the four extra blue coffee cups they were given and place them in each offspring box on the Punnett square Template (on top of the LEGOs®). See Figure 5.
   - At this point, ask students to think about why the brick and roof tile LEGO®/allele combination produces a blue cup and not a red one. This gets them to consider the idea of allele dominance before it is formally introduced.
   - Distribute two copies of the Punnett square Analysis handout (see Master 2). Instruct students to record the results of this first mating on the handout.
   - Ask student teams to complete the following matings and record the results on their Punnett square Analysis handout (see Master 2).

     Coffee Cup B (one brick and one roof tile inside) with Coffee Cup A (two bricks inside).

     Coffee Cup C (two roof tiles inside) with

Coffee Cup B (one brick and one roof tile inside).

- Discuss the results of the matings with the entire class.

Procedure: Part C

1. Introduce the following terms, writing definitions on the board, and illustrating with examples. Have students record definitions in their notes.

   genotype

   phenotype

   heterozygous/heterozygote

   homozygous/homozygote

   dominant allele/dominance

   recessive allele/recessiveness

2. Discuss phenotypic and genotypic ratios, demonstrating with the above matings (*optional*).

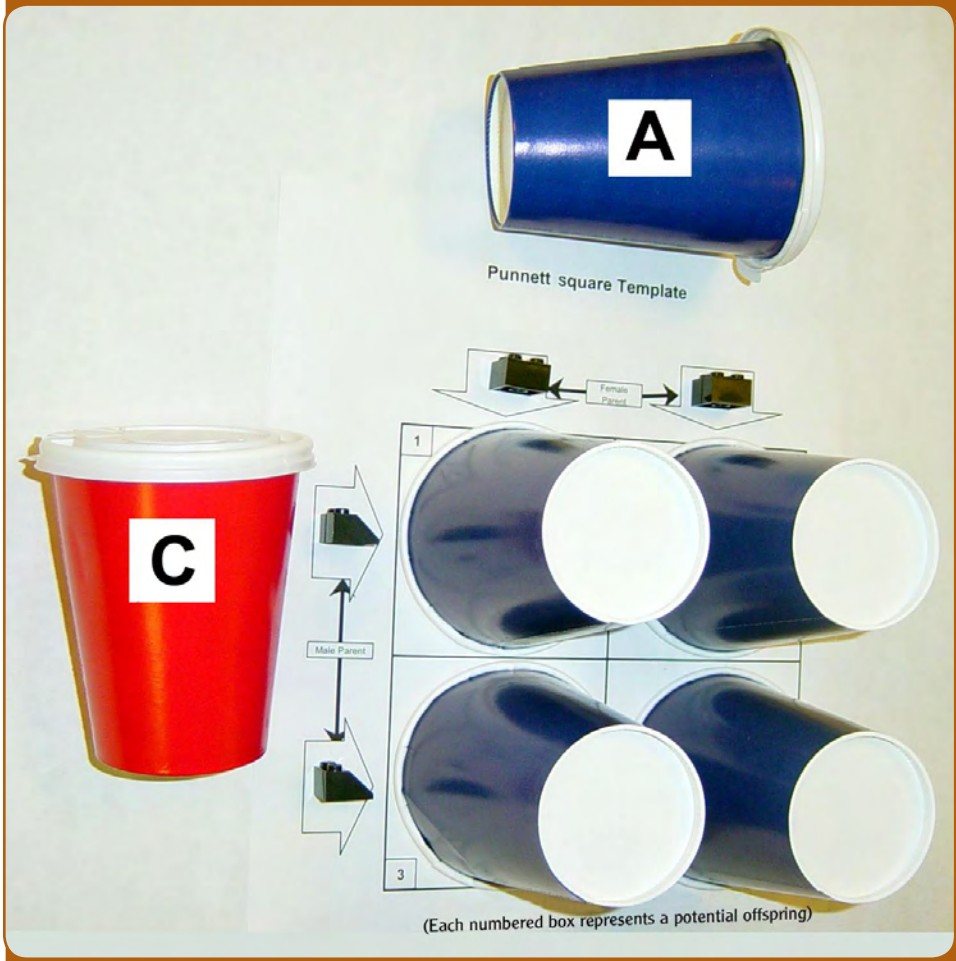
Procedure: Part D

In the following tasks, students demonstrate comprehension with their actions, not words. The easiest way to do this is to have all students hold up and use the appropriate materials to show their answers to the prompts listed below. This is a quick way to assess student understanding and identify and correct discrepancies. It also showcases the student who understands through his/her hands but has difficulty using newly acquired language to demonstrate his/her understanding.

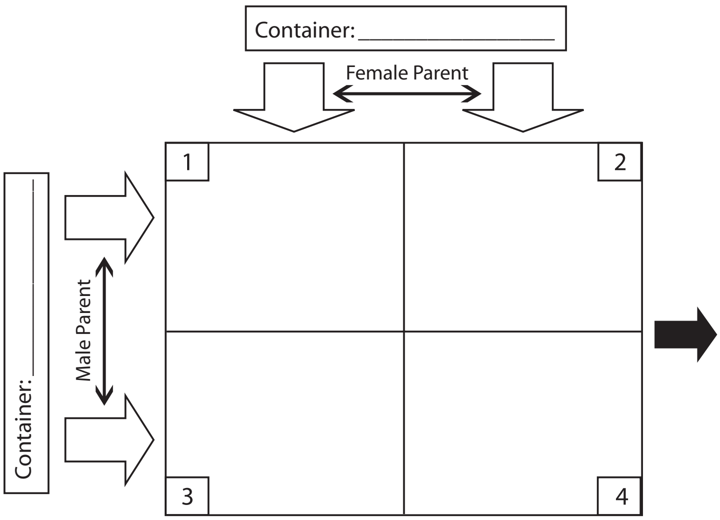
Write on the board the following tasks for all to see, so students can have a visual reference:

1. Show two possible phenotypes. *Students will hold up the two different colored coffee cups.*
2. Show the heterozygous genotype. *Students will hold up the roof tile/brick combination.*
3. Show a recessive allele. *Students will hold up the roof tile.*
4. Show three possible genotypes. *Students will hold up the two bricks, the two roof tiles, and the roof tile/brick combination.*
5. Show a dominant allele. *Students will hold up the brick.*
6. Show the homozygous genotypes. *Students will hold up the two bricks and the two roof tiles.*
7. To assess student use of the Punnett square Template, ask them to determine the potential offspring genotypes, phenotypes, and their ratios for all possible matings that have not been discussed. Use the newly-introduced terminology to describe the matings. At this point they may or may not need the manipulatives to solve the problems. Have them record their work on the Punnett square Analysis handout (see Master 2).
   - Homozygous blue coffee cup x homozygous blue coffee cup
   - homozygous red coffee cup x homozygous red coffee cup
   - heterozygous coffee cup x heterozygous coffee cup (the most interesting!)
8. Check and/or compare student teams' work.
9. Present and discuss with the entire class the following questions regarding the LEGO®/Coffee Cup analogy used in this activity for its genetic accuracy/educational value.

Figure 5.
Coffee cup phenotypes distributed in Punnett square Template.



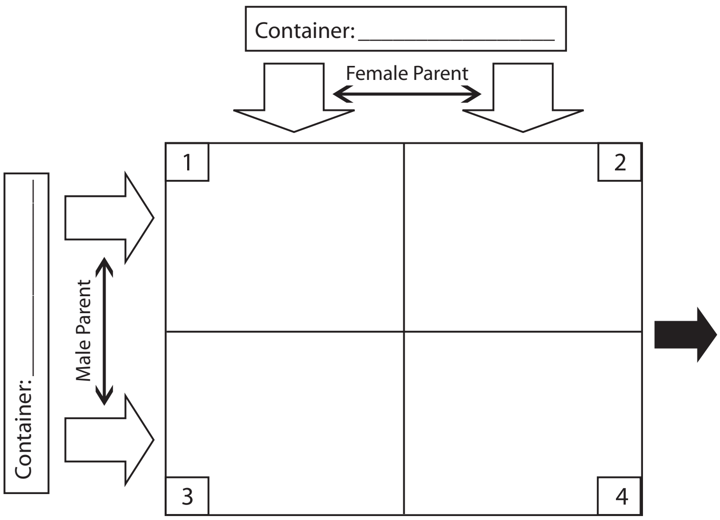
Master Two: Punnett square Analysis Handout



(Each numbered box represents a potential offspring)

Analysis Questions

1. How many different LEGO®/allele combinations are possible in offspring? ________________________
2. What is the probability of getting each combination? ________________
3. What color(s) will the offspring be? ________________________



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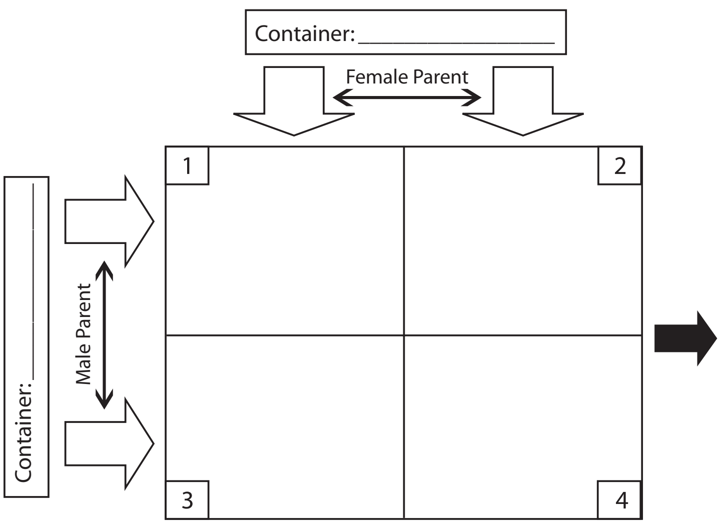

(Each numbered box represents a potential offspring)

Analysis Questions

1. How many different LEGO®/allele combinations are possible in offspring? ________________________
2. What is the probability of getting each combination? ________________
3. What color(s) will the offspring be? ________________________

- Question: What is accurate about this activity? *Answer: Genes do affect an organism's color. Genes come in different forms (alleles) that at a molecular level have different shapes, just like the two LEGOs®.*
- Question: What is oversimplified about this activity? *Answer: Color tends to be affected by more than one set of genes.*

10. Ask students to reflect on the activity: How well did the manipulative materials help you learn the genetics terms and concepts introduced? What was difficult for you about using the manipulatives?

Suggestions for Extended Learning

1. Once students have mastered the terms and tactile representations of the terms, introduce more traditional representations of Punnett squares using letter codes (i.e., AA, or aa) and classic genetics problems.
2. Use this same LEGO®/Coffee Cup setup and enhance it to teach additional concepts such as incomplete dominance, co-dominance, and dihybrid crosses.

   Incomplete dominance: This could be done by adding a third coffee cup color to the activity materials.

   Co-dominance: The classic ABO blood type example of co-dominance could be modeled by adding an additional LEGO® shape/allele to the materials, and two additional coffee cup colors, for a total of four phenotypes. (For instance: blue = A type; red = B type; purple = O type; and blue- and red-striped = AB type.

   Dihybrid crosses: This would be a lot more complex than the monohybrid cross, but possible. It would require:

   - a 16 box Punnett square Template
   - an additional phenotypic trait besides coffee cup color (such as two different lid styles)
   - two additional LEGO® shapes besides roof tiles and bricks (for the lid style alleles, for instance)

Conclusion

Using manipulatives to teach biology supports the idea that students learn in different ways and that concrete representations of abstract concepts may be an effective way for students to be introduced to challenging biology content. Informal surveys of instructors who have utilized this exercise have revealed that some students found it to be extremely effective in furthering their understanding of these abstract ideas. These same informal surveys also show that the instructors who used the exercise found that it improved student learning of Mendelian Genetics concepts. Naturally, some students who do not prefer tactile learning techniques might find this exercise confusing. These students might require additional instructional experiences in order to master the concepts. As instructors it is essential that we teach to the broad diversity of learning preferences among our students and not just to those students who happen to learn in ways aligned with our own teaching and learning style. Once an instructor becomes familiar with the logistics and educational value of using manipulative materials to teach, the possible applications within the introductory biology curriculum are boundless.

Acknowledgments

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