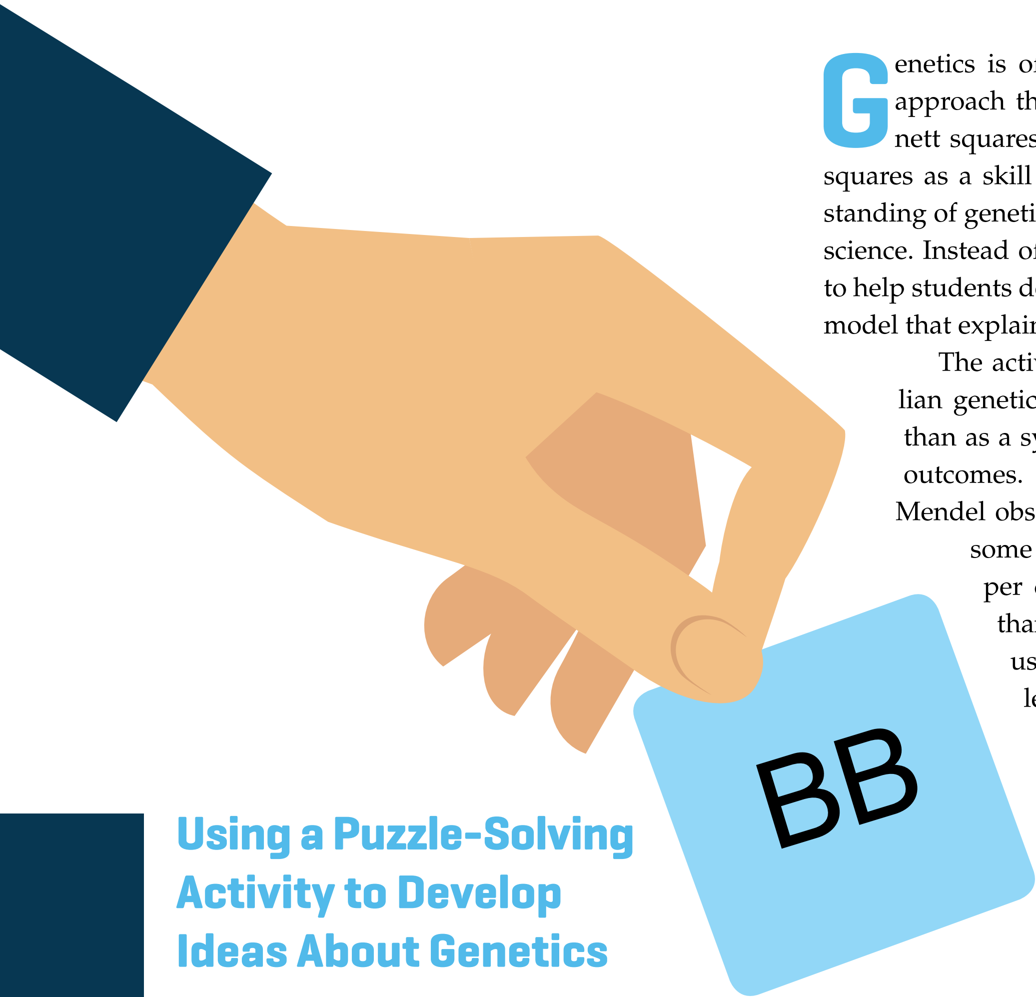
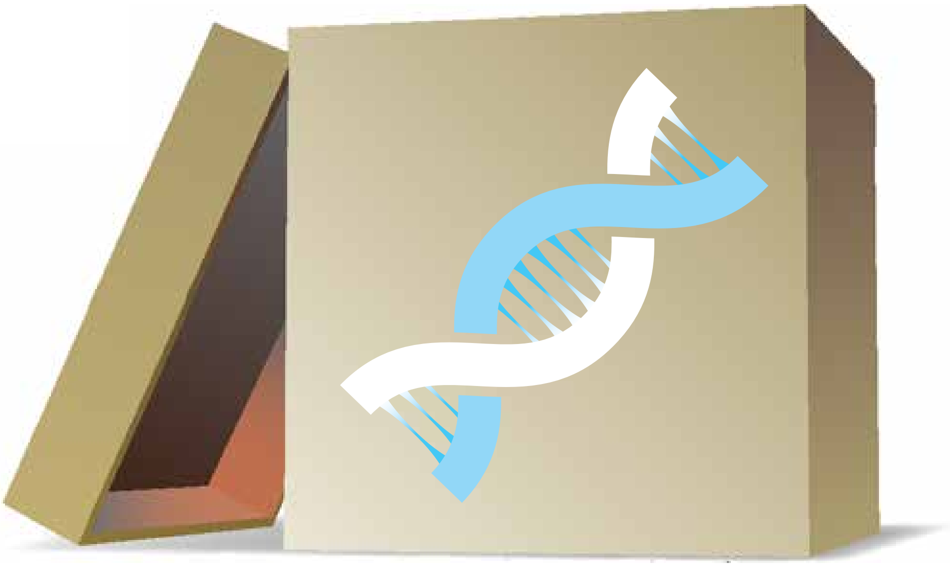
Modeling Mendel



Using a Puzzle-Solving Activity to Develop Ideas About Genetics

BY KAYLA BRAUER AND JERRID KRUSE



Genetics is often taught through a skill-based approach that models how to complete Punnett squares. Unfortunately, teaching Punnett squares as a skill does not promote a deep understanding of genetics and misrepresents the nature of science. Instead of a skill-based approach, we work to help students develop Punnett squares as a useful model that explains observed patterns.

The activity we describe presents Mendelian genetics as a puzzle to be solved rather than as a system of rules and predetermined outcomes. However, because the patterns Mendel observed are not quite as uniform as some might believe, we use colored paper crosses as our data source rather than actual plants. Furthermore, we use the puzzle-solving activity as a less contextualized way to introduce students to the nature of science (Clough 2006).

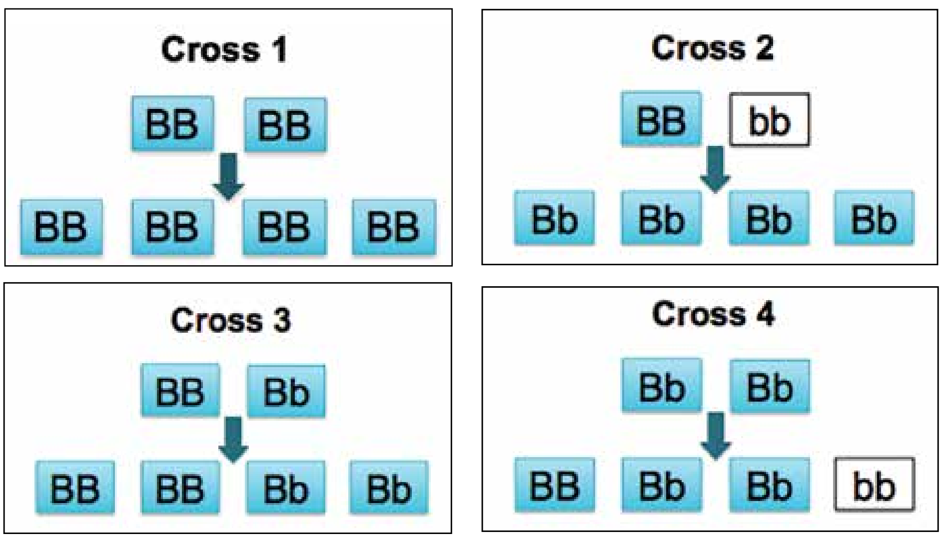
Setting up the puzzle

We begin this activity with cross one (see Figure 1) by showing students two blue cards being put into a shoebox. Students are not told anything about the cards in the box, just that putting cards in will result in cards coming out. (The cards going in the box are the parent generation, and the cards that are pulled out of the box as a result of that cross are considered the next generation, or F1.)

We tell students that we will be pulling four cards out of the box and encouraging students to make predictions about the color of those cards. As we pull out four blue cards, we ask students, "Why do you think the results turned out the way they did?" Students may surmise that all of the cards in the box were blue based on the fact that they observed you putting two blue cards in the box. At this point, we encourage students to make a note of their observations (or make a note on the board) and set the result cards of cross one to the side (sometimes using a document projector for students to see) for later use before we move on to the next cross. Students may come up with the idea later that not all cards are the same. For instance, one student may note that the blues look the same (phenotype), but they must be made up of different "stuff" because one results in white and the other doesn't. With my students, we talked about how we could label these with letters, but we need to use two letters to show how the two types of blues are similar, yet different. The goal is to eventually get students to the idea of alleles, but the cards themselves should not be labeled. I kept a sticky note in my hand to keep track of what was going in and coming out, as well as the result.

In the second cross (see Figure 1), we place one blue card and one white card into the box (the same box as before). Most students predict that two of the cards will be blue and two will be white, while others predict some sort of mix between the two. After students have an opportunity to share the reasoning behind their predictions,

FIGURE 1: Crosses 1–4 showing the alleles and color of each card



CONTENT AREA

Biology

GRADE LEVEL

6–8

BIG IDEA/UNIT

Introductory genetics, Mendelian genetics, patterns

ESSENTIAL PRE-EXISTING KNOWLEDGE

Observation and inference

TIME REQUIRED

90 minutes, or two 45-minute class periods

COST

None

SAFETY

N/A

we pull four blue cards from the box. Upon seeing this, most students claim that blue always "wins," so whenever a blue card is present in the mix, blue will be the result. When students express this view, we don't confirm or deny the idea and only ask students, "Why do you think that might be the case?" We set the resulting cards from cross two aside for later use and move on to cross three.

For the teacher

The shoebox contains approximately 20 blank blue cards and 20 blank white cards. The alleles are not written on the cards; it is up to the teacher and students to decide what goes in and comes out after the teacher starts with the initial cross (For this activity, we used cards that were roughly 7.6 cm × 7.6 cm or 3 in. × 3 in.)

The top of the box should be partially open so that the teacher can see inside but the students cannot. This allows the teacher to pull the correct color cards out of the box. I keep the box on my front table and have students stay at their desks during the input/output process when the top of the box is open.

The cards are set aside once they are drawn, unless students decide that they want to mix those cards again. If the cards are proposed as part of a future mix, they go back into the box. Otherwise, they remain off to the side. Students realize that there are more than two cards in the box after a couple of rounds of crosses. Most students predict that all of the cards will be blue, while some suggest a mix of blue with other colors.

Next steps

For cross three (Figure 1), we propose that students use one card from the results of cross one and one card from the results of cross two to create a new cross. Students almost immediately start making predictions, and we have to slow them down a bit by asking, "Why do you think you'll get all blue cards again?" and "Why do you think white might show up now?" After having students explain their predictions, we place the two cards in the box and pull out four blue cards. After the initial eruption of students claiming that they were right or contesting the results, we suggest one more cross: mixing two of the cards from the results of cross two.

When we perform cross four (see Figure 1), we pull out three blue cards and one white card. Some students claim, "I knew there was some white still in there" and others exclaim, "Now you're just messing with us!" We have students hooked at this point and can start moving toward trying to explain these results. We give students some time to talk in their groups or with partners to discuss the results and share ideas that might explain those results. During this time, we walk around and listen to students' conversations to encourage on-task behavior and keep frustrated students from giving up. After a couple of minutes, we give groups a more specific task by announcing, "I'm going to let you choose two of the cards we have (drawn previously) to cross. So, one member of your group will have to make a suggestion for a cross and explain why you want to complete that cross." We give students another three minutes to come up with their suggested crosses.

When we call the class back together, we ask one group what they would like to cross. Typically, at least one of the groups will simply ask us to cross two blue cards. We use this opportunity to ask the whole class, "To what extent does it matter which two blue cards we cross?" Some students claim that it doesn't matter, but others note that crosses three and four were all blue crossed with blue but had different results. After this short discussion, we make it clear that groups must tell us exactly which of the remaining cards to cross. If necessary, we give groups two more minutes to identify the specific cards. When students suggest crosses, we carry them out, using the key in Figure 2.

Teacher note: The teacher will need to be able to figure out the results of each cross as students put cards into the box and pull out the results. We kept a sheet of paper off to the side and out of students' view (Figure 2), to keep track of each cross and its results to support future discussion.

Introducing alleles

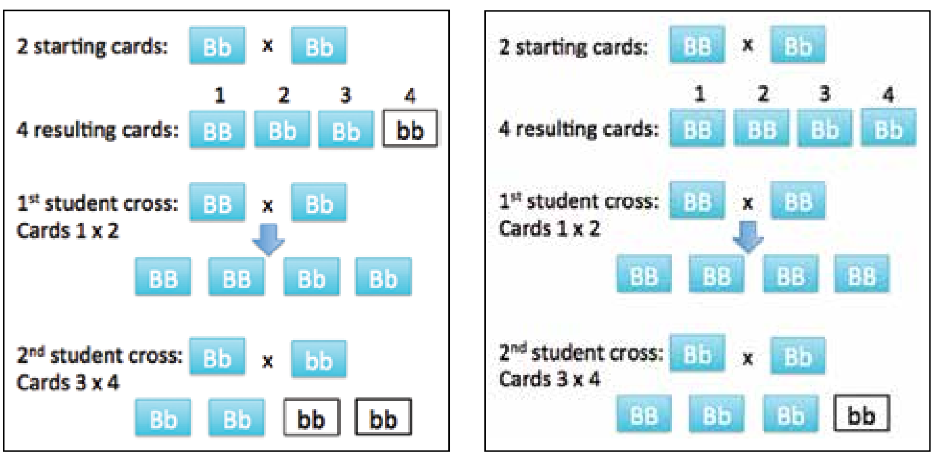
Based on the crosses, students start to claim that some of the cards have a blue and a white component. Some students refer to the blues as being "strong" or "weak." When asked, "What makes some blues strong and other blues weak?" students are able to describe that the weak blues have some white in them while the strong blues are pure blue. Other students said that strong blues are "double" blues, while weak blues have half blue and half white. So we ask, "How could we label the cards to show that they might have both a white and a blue component?" At this point, students might ask us to color in the strong blue cards we have drawn on the board. Other times, students may ask us to use letters such as "SB" for strong blue and "WB" for weak blue. After discussion about students' ideas, we offer a suggestion by asking, "If we marked each card with letters, in this case we'd use "B" for blue; how could we show that some blue cards are pure blue while others have a white component?" Students usually note that we could use capital letters for the pure blue and a lower case letter for the "weaker blue." We then ask, "You noted that some cards have both a blue and white component; why might using two letters help show the two components more clearly?" After some discussion, we suggest using a "B" for blue components and a "b" for the white components if students do not make the suggestion on their own. To ensure students understand the labeling system, we ask them how a white card should be labeled. When students recognize that the white cards would be labeled "bb," we know they are ready for the next section. Once students understand the labeling system, we briefly explain that the letters are called "alleles." We then ask students, "Why do you think a 'B' mixed with a 'b' results in a blue card?" When students explain that the "'B' is stronger than the 'b,'" we introduce the terms *dominant* and *recessive*.

Predicting outcomes

To help students move toward quantitative aspects of genetics, we ask, "How can we explain that two cards produce four new cards?" or "How might the numbers of each color help us explain why we get certain results?" Here students go back to the idea that each card is made up of two alleles. Some students compare the mixing to the distributive property in mathematics. That is, each allele from one card pairs with each allele from the other card, making four new card combinations. However, if students do not make this insight, we ask, "How do you think the alleles of each card interact with the alleles of the other card?" and "Why would this produce four cards?"

We ask students to test their thinking with a new cross by asking, "If we mix two strong blues, what will be the result if your ideas about how the letters interact are correct?" To further their investigation, we encourage additional predictions such as white with strong blue and weak blue with weak blue. When students claim that two weak blues will make three blue and one white, we look skeptical and ask them to explain why. Throughout this activity, students are prompted to talk in small groups and pairs. The teacher elicits multiple responses from different students throughout the activity. As students try to convince us of their result, they are also helping their fellow students gain understanding as to how they made their pre-

FIGURE 2: Example teacher notes for crosses



diction. Then, we ask students to identify two weak blues from the assortment of cards, and we test their prediction. In other words, students tell us which blues they believe are "weak" and support their rationale with their observations and inferences made as a result of their experience with the previous crosses. Students are excited to see that their prediction was accurate. With this understanding, students are now ready to be introduced to the more formal model: Punnett squares.

Punnett squares

While students conceptually understand that each card carries two alleles and that each allele of one card interacts with each allele in another card during a cross, they often do not create the typical grid format of a Punnett square. However, if students do want to create a grid, we encourage them to do so. If not, we draw a 2 × 2 grid on the board and ask, "How could we use this to make predictions about our crosses?" Typically, at least one student suggests filling the four boxes with our results, with one of the original card's alleles on the top and one on the side. To help students understand, we complete an example Punnett square with the class. While the Punnett square system makes sense to students almost immediately, we encourage them to think back on their investigation by asking, "How would your understanding of this Punnett square method be different if you had not struggled with the investigation we've been doing?"

Going beyond genetics

While approaching genetics as an investigation rather than a skill will support students' conceptual understanding, such an approach also provides great opportunity to engage students with the nature of science (NOS). Throughout this activity and at the conclusion of the activity, we encourage students to reflect on their work by asking questions such as:

- Notice how your thinking changed over time. What might cause scientists' thinking to change? Why is the ability for science ideas to change a good thing?
- You had to create an explanation to account for your observations. How does this illustrate that science is not based solely on evidence?
- You tested your ideas by making predictions. Why might scientists use predictions to test their ideas?
- In what way did your investigation require creativity? How might scientists use creativity?
- We talked in small groups and as a whole class. Why do you think collaboration is so important in science?

While we could ask all of these questions in a single discussion at the end of class, we work to bring these conversations in throughout the activity, as opportunities present themselves. We revisit the NOS throughout the school year (see Kruse 2008) and continue our genetics unit to help students understand how the ideas they have developed play out with real organisms.

REFERENCES

Clough, M.P. 2006. Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education* 15 (5): 463–94.

Kruse, J.W. 2008. Integrating the nature of science throughout the entire school year. *Iowa Science Teachers Journal* 35 (2): 15–20.

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standard

MS-LS3: Heredity: Inheritance and Variation of Traits
www.nextgenscience.org/dci-arrangement/ms-ls3-heredity-inheritance-and-variation-traits

Performance Expectation

MS-LS3-2. Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Developing and Using Models	Students use cards as models of genetic crosses to explain patterns.
Disciplinary Core Idea	
LS3.B: Variation of Traits • In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other.	Students answer the following questions: • You noted that some cards have both a blue and white component. Why might using two letters help show the two components more clearly? • How do you think the alleles of each card interact with the alleles of the other card?
Crosscutting Concept	
Cause and Effect	Students develop cause-and-effect relationships to predict outcomes of genetic crosses by answering questions such as, "If we mix two strong blues, what will be the result using your ideas about how the letters interact?"

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