Geniverse Teacher Guides

Training Level Teacher Guide

A) Overview

The Training Level introduces the Geniverse software, and guides students to make connections between genotype, phenotype, meiosis and fertilization. Students are also introduced to the process of constructing scientific explanations or "arguments" (making a **claim**, providing appropriate **evidence**, and explaining their **reasoning**), and finally are challenged to bring together all of these lessons in a Certification Exam that requires that students demonstrate an understanding of the material learned thus far and an understanding of test crosses. Students explore the inheritance of metallic and nonmetallic coloring, as well as the presence or absence of wings, forelimbs, and hindlimbs. At this Level, each gene has only two possible alleles and behaves according to the classical Mendelian dominant/recessive model. The next levels of Geniverse will explore more complex gene interactions.

Items unlocked in this level: The first cartoon panel of Arrow's continued story (after Case 5)

Five Cases comprise the Training Level.

Case 1: Enter the Drake, contains a pre-activity and two short Challenges.
Case 2: My, Oh Sis, contains a pre-activity and two Challenges.
Case 3: In the Clutches of Drakes, contains two Challenges.
Case 4: Settle the Argument is a single Challenge.
Case 5: The Certification Exam is a single Challenge.

B) Learning Goals

By the end of the Training Level, the following learning goals are addressed specifically for dominant /recessive traits:

Students will know that…

1. genes exist in different forms called alleles.
2. some traits result from a single gene.
3. for some single-gene traits, some alleles are dominant to others, and that a dominant allele will mask the presence of the recessive allele in external phenotype.

4. meiosis reduces the genetic information in each cell by half; the resulting cells are gametes (egg and sperm).
5. during meiosis one member of each pair of chromosomes moves randomly into a gamete.
6. organisms normally receive two copies of each chromosome, one from each biological parent, and that this occurs when an egg and sperm join during fertilization.
7. the chromosomes an offspring receives from each parent may have the same or different alleles for each of the genes.

Students will be able to…

1. predict an organism's genotype based on its phenotype.
2. predict an organism's phenotype based on its genotype.
3. use parental genotypes to predict the set of offspring phenotypes.
4. use a test cross to determine unknown genotypes.
5. recognize a claim as a statement of what is thought to be true about how a genetics phenomenon works.
6. use a model to generate gametes with a set of chromosomes that can generate a specific offspring phenotype.
7. with scaffolding, provide evidence to support a specific claim.
8. with scaffolding, provide reasoning that explains why the evidence supports the specific claim.

C) Case 1: Enter the Drake

Overview

Case 1 focuses on the relationship between genes and traits in adult drakes. Four drake genes-wings, forelimbs, hindlimbs and metallic color-coded for by alleles on three chromosome pairs, are manipulated with pull-down menus. Students immediately observe any change in phenotype as they change the genotype. They also experience changes in genotype that do not result in a change in phenotype. Students should begin to consider rules for inheritance of these four single-gene traits.

There are three activities in Case 1.

The first activity is the **Playground**, where students experiment with pull-down menus representing the alleles for four drake traits. Students should consider what possible rules might be governing the patterns of inheritance for these four traits. When they feel ready, students move forward by clicking the green arrow or the "Bring it on!" button.

Challenges 1 and 2 asks students to predict phenotypes in a reliable way by choosing appropriate alleles to match target drakes. In Challenge 1, students match a single target and move on to Challenge 2 where they must successfully match a series of 3 targets.

Preparing for Case #1

1. Review the lesson plan for Case #1 and play through the challenges in this case.
2. Determine whether or not students should work solo or with peers. Have a plan for what students should do if they finish before others.
3. The teacher may choose to make use of the electronic notepad available from within the software, use the relevant handouts, or devise another means of having students record their work.
4. Ensure that students will be able to successfully navigate the Geniverse environment. The User's Guide provides a related screencast.

Considerations for Case #1

1. The software randomly generates the drakes that are presented in each challenge.
2. All challenges in this case are game-like and students earn stars. Three stars are automatically awarded for doing anything within the Playground activity.
3. It is best not to interrupt the flow of this game-like experience too much. Still, students will need ample time to make sense of what they experience in order to build their understanding. This can happen at the end of the case and might include discussions.
4. We recommend against front-loading students with genetics vocabulary. Students can describe allele interactions using basic language for now (e.g.- a drake with one wing and one no-wing will have wings).
5. If students are guessing rather than systematically trying to predict phenotype from the genotypes they choose, try asking a question like, "Why did you choose this allele combination?"
6. Students may notice that there is an additional allele shown for nose spike on the X chromosome. This is not called out specifically in this level, but is presented intentionally to allow students to notice this difference between males and females and to prepare them for later thinking about sex-linked traits.

Potential trouble spots

1. Students frequently forget to check the sex of the drake when trying to match the targets. Sex can be changed using the male/female toggle switch as shown below. The green background indicates the active state of the toggle. How do you know if your drake is a boy or a girl? Make drakes have neck waddles (like a turkey) and females do not. The difference in the neck looks like this:

Male	**Female**

	

To change the sex of a drake, use these toggle buttons. The one that is highlighted in green is the sex of the current drake.

When this button is green, it shows that the drake is male.

When this button is green, it shows that the drake is female.

Key points

1. A winged drake will have either one or two “wing” alleles (wings/no wings or wings/wings). When there is only one wings allele, it does not matter which chromosome it’s on.
2. A wingless drake must have two “no wing” alleles (no wings/no wings).
3. The metallic, forelimb and hindlimb traits work the same as wings.

Questions for deeper thinking

1. Why do you think some traits appear even when there is only one allele for it? (*Possible answers might refer to dominant/recessive, if students have heard these terms before. They may also present varied explanations of that concept in common language. Students might also recognize the single gene on the X chromosome in the male drake.*)
2. Can we ever know precisely what alleles a drake has for a particular trait based on the way it looks? (*Yes, for any homozygous recessive trait - such as wingless - you can tell that there are two no-wing alleles for that specific trait.*)

Underlying genetic mechanism

All four traits in this case follow standard Mendelian dominant/recessive inheritance where the metallic, wings, forelimbs and hindlimbs alleles are the dominant ones.

The real genes behind these traits
All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

D) Case 2: My, Oh Sis!

Overview

Case 2 introduces the basic concept of meiosis and the user interface of the meiosis tool.The meiosis tool enables students to observe gamete formation and independent assortment of chromosomes. The model also allows for selection of gametes and fertilization, producing an offspring drake. Students do not need to know about meiosis in advance. The model is intended to present the basics of meiosis in a way that allows students to explore connections between meiosis and inheritance of traits at both the genotypic and phenotypic levels. The model is intended to lay the groundwork for understanding the similarity and variation among offspring of the same parents. Case 2 guides students to understand how specific offspring outcomes are possible, and prepares them for the thinking they will need to do in subsequent Cases as they breed clutches of 20 offspring.

There are 3 activities in Case 2:

The first activity is the **Playground**, where students experiment with the meiosis model by dragging one parent at a time into the Parent Drake circle and clicking the Play button. Students watch how the parent's chromosomes separate during meiotic production of sperm or eggs. By clicking the Retry button, students see that meiosis does not sort chromosomes the same way each time. When ready, students can click either the green forward button, or "Bring it on!" to move to Challenge 1.

Challenges 1 and 2 present very powerful interactive experiences for students, moving them from adult organisms, through the possible gametes that the drakes could create, to fertilization of chosen gametes, and finally to the specific offspring that the student's chosen gamete combination creates. In each of these Challenges, students must match target drakelings by selecting the correct gametes from a mother and father drake. In the second of these two Challenges, students must first identify which of two mother drakes is capable of producing the necessary egg.

Preparing for Case #2:

1. Review the lesson plan for Case #2 and play through the challenges in this case.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.

3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.

Considerations for Case #2

1. All students receive the same parent and target drakes in each challenge.
2. All challenges in this case are game-like and students earn stars. Three stars are automatically awarded for doing anything within the Playground activity.
3. This case can be completed fairly quickly, so it is probably best to save formal sense-making activities, including discussions, for after its completion.
4. We recommend against front-loading students with information about meiosis other than it's main purpose. Allow students to explore meiosis as it relates to passing on traits. Use follow-up time to review key aspects of meiosis and to add details relevant to your specific circumstance.
5. Crossing over is addressed in Case 7.
6. There are two aspects of this case for students to think about, 1) the purpose and general process of meiosis, and 2) how meiosis is connected to inheritance of traits. It might be useful to address these one at a time.
7. During Challenges 1 and 2 it is often necessary to use the retry button repeatedly to produce a sperm cell with the necessary assortment of alleles.
8. The meiosis model can be used to help students explore the ways in which models are useful simplifications. This aligns with Scientific Practice 2 and Cross-cutting Concept 4 in the *Framework for K-12 Science Education*.

Potential Trouble Spots

1. Students may become frustrated trying to make the Meiosis engine work. Check with them to be sure they understand how to select a parent and run meiosis, how to select gametes, and how to generate an offspring. Refer to the User Guide if necessary.
2. Meiosis runs slowly, but after viewing it a few times, much frustration can be avoided by clicking the "end" button after initiating meiosis.
3. Students tend to get frustrated with needing to retry meiosis multiple times in order to acquire the necessary combination of chromosomes and alleles. Clicking the "end" button after clicking "retry" speeds things up. If students persist in being frustrated, it may be a good idea to discuss how this reflects reality.

Key points

1. Living things have two alleles of each gene, one located on a chromosome received from the mother and the other copy on a chromosome received from the father. These alleles may or may not be identical.
2. Egg & sperm cells resulting from meiosis have only ½ set of chromosomes. This means each egg has only one allele of each of mom's genes and each sperm has only one allele of each of dad's genes.

3. Assortment of chromosomes into the different egg or sperm cells during meiosis is random and therefore different each time. This means that each egg in a female has a different combination of half of the alleles of her genes. The same is true for each sperm a male produces.
4. Although one can select the gametes in Geniverse, in reality fertilization is random. The randomness of fertilization results in similarities & differences between offspring from the same set of parents.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. In families of blood relatives, children look like their parents, but not exactly, and siblings resemble each other, too. How does meiosis help explain such observations?
2. What is the impact of meiosis on the inheritance of traits?
3. How would you describe the importance of meiosis to the continuation of a species through time?

The Answers

1. **Challenge #1:**
    a. To match the first target, one needs a female gamete with the forelimbs/no hindlimbs combination, plus a male gamete with an X chromosome and either the forelimbs/no hindlimbs combination or the no forelimbs/no hindlimbs combination.
    b. To match the second target, one needs a female gamete with the forelimbs/hindlimbs combination, plus a male gamete with a Y chromosome and either the forelimbs/no hindlimbs combination or the no forelimbs/no hindlimbs combination.

2. **Challenge #2:** The second mother is the one that can create both offspring.
    a. To match the first target, one needs a female gamete with the no forelimbs/no hindlimbs combination, plus a male gamete with an X chromosome and the no forelimbs/hindlimbs combination.
    b. To match the second target, one needs a female gamete with the no forelimbs/no hindlimbs combination, plus a male gamete with a Y chromosome and the no forelimbs/hindlimbs combination.

Underlying Genetic Mechanism

All four traits in this case follow standard Mendelian dominant/recessive inheritance where the metallic, wings, forelimbs and hindlimbs alleles are the dominant ones.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

E) Case 3: In the Clutches of Drakes

Overview

Case 3 introduces students to an interface for breeding drakes. Students apply their learning from the first two Cases to a novel task that combines pull-down menus and breeding outside of the meiosis tool. Students continue using the same four, dominant/recessive traits to solidify the link between genotype and phenotype by considering how to set parents' alleles so that specific target offspring can be produced through breeding. The "stats" tab is available for the first time, and students may wish to explore it, but its use is not required for completion of this case.

There are two activities in Case 3:

In both **Challenges 1 and 2** students manipulate one parent's alleles so that the parents can have offspring that match the target drake(s). In the first Challenge, the male parent's alleles are fixed and students must match only one target. In the second Challenge, the female's alleles are fixed and students must match two targets from the same mating pair of drakes, although they may need to hit the breed button more than once. Students are awarded the appropriate number of gold stars for each case.

Preparing for Case #3

1. Review the lesson plan for Case #3 and play through the challenges in this case.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.

Considerations for Case #3

1. All students receive the same parent and target drakes in each challenge.
2. The challenges in this case are all game-like and students earn stars.
3. Since this case can be completed fairly quickly, it is probably best to save formal sense-making activities, including discussions, for after its completion.
4. Because offspring drake alleles are randomly generated from parental alleles, it may take students several clicks of the breed button to match the targets in one clutch, even if the parents' alleles are set correctly.
5. Students must think through possible combinations of parents' alleles in order to create target drakelings without relying on luck. They will be working out something analogous to a Punnett square, though they are unlikely to use that exact method unless already familiar with it. We recommend against introducing Punnett squares until sometime between Cases 4 and 6. Instead, have students share their thinking about how the parents' alleles might combine in the

offspring and encourage them to communicate this thinking through drawings, lists, etc., rather than trying to envision it all in their heads.

6. Now or after completion of the Training Level is a reasonable time to address Mendel's work and its connections to Geniverse.

Potential trouble spots

1. Models have limitations and one of the limitations to this Meiosis tool is the risk of perpetuating the idea that one can select which alleles will be passed to one's offspring. It might be a good idea to remind students that this is not possible in reality (so far).
2. Students may not realize that changing parent drake alleles using the pull-down menus results in their actually generating a new parent drake, one with a different set of alleles than the previous one. This situation is analogous to the TV shows *The Bachelor*, or to the older version, *The Dating Game*. The one person who is constant, the bachelor, is analogous to the drake whose alleles are fixed. As each bachelorette or contestant comes into the picture, this is analogous to the changing of the other drake's alleles using the pull-down menus; each allele alteration results in a new "contestant" for producing the required target drakes when mated with the fixed-allele parent.

Key points

1. No new information is presented during this case.
2. It may be a good time to review key points from the past two cases, applying them to this particular set of challenges.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. How could you increase the likelihood that you would get a clutch of baby drakes with no wings (or no forelimbs, no hind limbs or nonmetallic color)?
2. If you didn't know the parents' alleles and could only look at the offspring traits, could you say with *certainty* what the parents' alleles were? Could you say what they *probably* were? Support your answer; use an example if necessary.

The Answers

To solve Challenges 1 and 2 in the fewest number of moves, one has to understand that for an offspring to be metallic, or have wings, forelimbs, or hindlimbs at least one parent must have one of those alleles. However if an offspring is non-metallic, has no wings, no forelimbs, or no hindlimbs, each parent must have at least one of those alleles.

Underlying Genetic Mechanism

All four traits in this case follow standard Mendelian dominant/recessive inheritance where the metallic, wings, forelimbs and hindlimbs alleles are the dominant ones.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

F) Case 4: Settle the Argument

Overview

Case 4 introduces students to the in-game scaffold for scientific argumentation. It models what a claim can look like, and then gives students practice in providing evidence and reasoning to support a claim. This case contains a **single challenge** that begins with a cartoon showing each of four Geniverse characters offering a claim to explain the inheritance of genetic traits. Three of the four claims presented are based on common student misconceptions. Students create parent drakes using pull-down menus and perform breeding experiments to collect evidence to support the claim of their choice. They then apply reasoning to link the evidence to the claim. Students can post their arguments in the *Journal of Drake Genetics* or share them by some other means determined by the teacher.

Preparing for Case #4

1. Review the lesson plan for Case #4 and work through the challenge.
2. Review the scientific explanation framework (claim, evidence, reasoning) with students.
3. Determine the following in advance:
   a. How to group students for this challenge.
   b. Whether or not students will record their claims, evidence and reasoning in the Journal of Drake Genetics or by another means.
   c. Whether or not students will present their scientific explanations and have them critiqued.
   d. How students' scientific explanations will be evaluated. If so, provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answers section at the end of this case.
   e. If students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.

Considerations for Case #4

1. Each student receives randomly generated parents at the start of this challenge.

2. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised.
3. In order for students to benefit from sharing and critiquing arguments, it is important to first establish classroom norms that support the process and help students feel safe and respected as they contribute their ideas.
4. The research is clear that the more students talk about science concepts, the better they understand them. Engaging students in scientific argumentation by having students present and defend their scientific explanations and having them critiqued is one means of accomplishing this.
5. This challenge is an elaboration on student prior learning, requiring them to coalesce their understanding into a single claim supported by evidence and reasoning.

Potential trouble spots

1. Even students experienced with making claims supported by evidence and reasoning struggle with applying the framework in new or different content areas. They will need help identifying what counts as evidence in genetics, as well as in defining the principles that can be used as reasoning to link their evidence to their claim.
2. Like any skill, learning how to appropriately critique classmates' arguments takes practice and guidance, at least initially. This critiquing form may be useful.
3. This challenge is about how drakelings inherit genes from their parents, but students often confuse "genes" with "traits" and/or "appearance" (phenotype). When a student makes one parent homozygous-dominant for each trait and the other parent recessive for each trait, the offspring all have the phenoptypes associated with the first parent. Students often consider this as proof that the offspring got all their "traits" from the first parent and use this as evidence in support of Tars', Zander's or Zenda's claims. In such cases, students are not thinking about the genetic mechanism behind the phenotype, and it is important for such "evidence" to be challenged. Questions like the following can be useful to this end:

   a. Is that always true?
   b. How would your argument be affected if you had made the mother ___ and the father ___?
   c. How much genetic information for each trait did the offspring get from the mother? From the father?
   d. How can you use the process of meiosis as evidence to support or refute that claim?

Key points

1. The most accurate claim is that of Tamora, "Baby drakes get half their genes from their father and half from their mother."
2. At this point, there are two scientific principles students can draw upon to link their evidence to their claims.

a. For dominant/recessive traits, organisms with one copy of each allele display the dominant version of the trait because that allele masks the recessive one.
b. One copy of each chromosome moves into each gamete during meiosis, therefore offspring receive only one copy of each gene from each parent.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. How can we explain the difference between the terms *gene*, *trait*, and *phenotype*? (*If students have not already been introduced to the term phenotype, now might be a good time to do so.*)

The Answers

Claim: Tamora is right, baby drakes get half their genes from their father and half from their mother.

Evidence: Students should provide data from relevant breeding experiments, including links to the breeding records.

- This will likely take the form of multiple breeding experiments. If so, the combination should be sufficient and adequate to prove their claim.
- Students especially struggle with adequate (see Potential Trouble Spots).
- At this early stage, few students are likely to realize that breeding a heterozygous female to a homozygous recessive male will eliminate three of the four claims in a single experiment, as would breeding two heterozygotes. Each on its own is both sufficient and adequate to support Tamora's claim and disprove the other three.
- Students may also breed a set of drakes once, when 3-5 times would be more appropriate because it provides a larger sample size.

Reasoning: At this point, there are two scientific principles students can draw upon to link their evidence to their claims.

- For dominant/recessive traits, organisms with one copy of each allele display the dominant version of the trait because that allele masks the recessive one.
- One copy of each chromosome moves into each gamete during meiosis, therefore offspring receive only one copy of each gene from each parent.

Underlying Genetic Mechanism

All four traits in this case follow standard Mendelian dominant/recessive inheritance where the metallic, wings, forelimbs and hindlimbs alleles are the dominant ones.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

G) Case 5: Certification Exam

Case #5 is the final case in the Training level and it involves a **single challenge** in which students combine manipulating drake genes, breeding, observing offspring phenotypes, and their understanding of how dominant/recessive traits are inherited. Unlike prior challenges where students worked from cause to effect (genotype to phenotype), this activity asks them to think the problem through from effect to cause (phenotype to genotype). Students are presented with a male drake of unknown genotype, but with a fixed and defined phenotype, and a female drake whose alleles can be manipulated. Students must select the female's alleles so that after breeding the offspring will reveal information about the male's genotype.

After successfully completing Case 5, the next part of Arrow's story is unlocked, providing a little more information about his illness.

Preparing for Case #5

1. Review the lesson plan for Case #5 and play through the challenge.
2. Determine what students should do if they finish the case early.
3. Determine if students will use the relevant handout to record responses in addition to submitting them in the software.
4. Determine how to incorporate the story element that unlocks upon completion of this case.

Considerations for Case #5

1. Each student receives a different, randomly generated male drake of unknown genotype, but with a fixed and defined phenotype, and a female drake whose alleles can be manipulated. If a student retries the activity to earn more stars, they will receive a new male drake.
2. Moves are not counted here. The computer awards stars based on the number of attempts it takes to submit the correct answer.
3. Students who solve this by trial and error will be awarded only a single star. To avoid this, consider requiring that students repeat the certification exam until they earn at least two stars.
4. This challenge introduces the idea of a test cross (breeding to a homozygous recessive organism) without using the term. The teacher should decide whether or not to use the term based on their students' needs and readiness.

Potential Trouble Spots

1. This problem can be solved by making the female heterozygous for each trait. While this works, it is most efficient to use a test cross to determine an unknown genotype. Consider having

students share their approaches to solving this challenge, once everyone has had a chance to complete it.
2. Some students might have difficulty trying to solve the genotype for all the traits at once. As long as students stay logged into this Case, they may click “Ready to Answer”, select the genotype for one or more of the traits, then select “Return to the Lab” to explore further. They may do this repeatedly without losing prior genotype selections. The computer scores the choices only after one clicks “Submit”.

Key points

1. A recessive phenotype indicates a homozygous recessive genotype.
2. The genotype of an individual with a dominant phenotype is ambiguous and can be inferred by breeding with a homozygous recessive individual and observing the phenotypes of the offspring. *(Note that students do not need to see a particular ratio in the offspring; a single recessive individual is enough to detect the presence of a recessive allele.)*
3. Breeding to a recessive individual in order to infer genotype is called a *test cross.*

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. What are the different ways to solve this challenge?
2. Why might a test cross be a useful strategy for someone like a breeder of pets?

The Answers

Answers will vary, because each student receives a different male drake of unknown genotype. However, if the male is mated to a female with all recessive traits and

- Is non-metallic or has no wings, no forelimbs or no hindlimbs, then he is homozygous recessive for that trait.
- Is metallic or shows wings, forelimbs or hindlimbs and produces any offspring that are non-metallic or show no wings, forelimbs, or hindlimbs, then he is heterozygous for that trait.
- Is metallic or shows wings, forelimbs or hindlimbs and produces offspring all showing the same, then he is homozygous dominant for that trait.

Underlying Genetic Mechanism

All four traits in this Case follow standard Mendelian dominant/recessive inheritance where the metallic, wings, forelimbs and hindlimbs alleles are the dominant ones.

The real genes behind these traits

All drake traits are based on genes from real organisms like mice and anole lizards. Stay tuned for this information as we continue to build these materials.

Apprentice Level Teacher Guide

A) Overview

At the Apprentice Level students are introduced to more complex genetic mechanisms and to using quantification to understand and document inheritance mechanisms. Students are also introduced to recombination through the meiosis tool first used during Case 2. At this level, students have fewer opportunities to manipulate alleles and must rather breed parent drakes to solve most challenges. They have the ability to save bred drakes to the stable and use them in breeding experiments. They gain the ability to see the statistics relevant to each parent cross, and they gain the ability to "see" allele combinations for some genes using the magnifying tool.

Each of the traits introduced at this level is more complex than the training level. Horns are an example of a trait where the absence of a characteristic is dominant over its presence. The three tails are a result of a polyallelic series. The nose spike is a sex-linked trait. By the time students are "certified" to move on to the Journeyman level, they will have gained an understanding of some non-Mendelian inheritance mechanisms and will have gained experience in recognizing the patterns that can help to explain them.

Items unlocked in this level:

- The Apprentice Level of the Gene-to-Protein Genie (after Case 6)
- The Advanced Apprentice Level of the Gene-to-Protein Genie (after Case 9)
- The second cartoon panel of Arrow's continued story (after Case 10)

Five cases comprise the Apprentice Level.

Case #6, *The Horns Dilemma*, contains one argumentation activity.
Case #7, *What Are the Odds*, contains four challenges.
Case #8, *A Tale of Three Tails*, contains a pre-activity and two challenges.
Case #9, *Like Father, Like...*, contains three challenges, one of which is an argument activity.
Case #10 is a *Certification Exam* composed of two challenges.

B) Learning Goals

The following learning goals are addressed by the end of the Apprentice Level:

Students will know that...

1. For some traits primarily influenced by a single gene, some alleles are dominant to others. A dominant allele will completely mask the presence of the recessive allele in external phenotype.
2. Genes exist in different forms called alleles. There are usually more than two alleles for a gene, resulting in more than two phenotypes.
3. Some traits show patterns of inheritance that follow the inheritance of sex chromosomes because those genes are on a sex chromosome.
4. Specific combinations of parents' alleles result in characteristic patterns in the proportions of offspring.
5. Genes that are on different chromosomes assort independently during meiosis (as Mendel observed).
6. Meiosis reduces the genetic information in each cell by half; the resulting cells are gametes (egg & sperm).
7. During meiosis, paired chromosomes swap information through crossing-over events.
8. Organisms normally receive two copies of each chromosome, one from each biological parent. This occurs when an egg and sperm join (fertilization).
9. In some animals, sex is determined by the combination of sex chromosomes received from the parents. For example, in humans females are XX while males are XY. (Sex determination in drakes is modeled after humans.)
10. In sexually reproducing organisms, independent assortment and recombination of chromosomes during meiosis lead to a great variety of gametes. This in conjunction with sexual reproduction explains the similarities and differences observed between parents and offspring and between siblings.
11. Together, meiosis and sexual reproduction explain the similarities and differences observed between parents and offspring and between siblings.

Students will be able to…

1. Predict possible genotypes for an organism based on its phenotype.
2. Use numerical patterns in the phenotypes of the offspring to determine the genotype of the parents.
3. Predict an organism's phenotype based on its genotype.
4. Use parental genotypes to predict the set of offspring phenotypes and their approximate proportions.
5. Use a model to generate gametes with a set of chromosomes that can generate a specific offspring phenotype.
6. Use a test cross to determine unknown genotypes.

C) Case 6: The Horns Dilemma

The **single challenge** in Case 6 revisits the framework for scientific argumentation where students must determine whether the presence of horns is dominant or recessive, building upon students' existing understanding of dominant/recessive traits established during the Training level.Students are unable to manipulate alleles in this challenge, and the horn genotypes for the parents they receive are not visible. Students should be able to recognize patterns associated with test crosses and with breeding heterozygotes, and be able to apply these patterns to The Horns Dilemma in order to answer the question: "Are horns dominant or recessive?" The case culminates with students submitting an argument about the inheritance of horns.

Preparing for Case #6

1. Review the lesson plan for Case #6 and work through the challenge.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. The chromosome-viewing tool and stable are available to students for the first time. Review their use in the User Guide.
5. Determine when and how you will convene the class for a large-group discussion.
6. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.

Considerations for Case #6

1. All students receive the same set of parents at the start of this case.
2. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised.
3. Be prepared for some students to find it distasteful that drake offspring can be bred to each other or back to their parents. If this comes up, explain that it is a common practice in animal breeding for pets and livestock.
4. Using letter notation for alleles, such as Aa for heterozygotes, allows students to illustrate the sorting of alleles into gametes and the potential gamete combinations during fertilization. If they have not already learned such notations, now is a good time to introduce them.
5. Students need only recognize that if even a single offspring shows a phenotype for a particular trait that the parents don't display, the parents must be heterozygotes. Although Punnett squares are not necessary to solve this challenge, introducing them sometime during this case is a good idea. Students are more receptive to the Punnett Square when it is viewed as a useful tool for predicting offspring from a set of parents, something they'll have to do more of soon.

6. Students can become very good at solving even complex Punnett square problems, but have no understanding of their purpose or of the underlying mechanism of meiosis. Be prepared to help them make these connections.
7. At the conclusion of this challenge, it can be helpful to provide students with other examples of traits where the absence of something is dominant, e.g.- polydactyly in humans or the polled (hornless) gene in cattle.

Potential Trouble Spots

1. It might be helpful to have students review what they've already learned about inheritance of traits by referring them back to earlier challenges where alleles were visible and could be manipulated.
2. If students struggle with choosing which drakes to breed in Case 6, or with analyzing the results of a breed, consider using guiding questions such as:

   a. When you bred these two drakes and got these offspring, what does that data suggest about the genotypes of the parents?
   b. How did this set of parents produce offspring with this/these phenotype(s)?
   c. How can you predict the offspring you'd get from this pair of drakes (point to a pair they have not bred)?
   d. What different patterns do you expect to see in the offspring when you breed two homozygotes vs. two heterozygotes?
   e. Students who firmly hold the belief that the presence of a trait (wings, limbs, horns) indicates dominance may struggle with accepting their data and what it indicates. For these students it is especially important for them to engage in conversations with each other where they must use their evidence to support their claims.

Key points

1. Presence of a trait does not mean that it is dominant; the absence of a trait can be dominant. Having horns is recessive while being hornless is dominant.
2. In the case of dominant/recessive alleles, heterozygotes display the dominant phenotype. However, when both parents carry the same recessive allele, the recessive phenotype can appear in the offspring.
3. There are three principles students can draw upon to link their evidence to their claims in their reasoning section.

   a. One copy of each chromosome moves into each gamete during meiosis, therefore offspring receive only one allele of each gene from each parent.
   b. The phenotype of the offspring depends upon the combination of alleles received from the parents. For dominant/recessive traits, organisms with one copy of each allele display the dominant version of the trait because that allele masks the recessive one.

c. Students who have noticed the 3:1 ratio that results from breeding two heterozygotes can use this in support of their conclusions.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. What does it take to be sure of an answer when the "real" answer is not yet known by anyone?
2. As a scientist, how does one know whether or not the results of an experiment support one's hypothesis?

The Answer

Students are given two female and two male parents. One of each sex has horns, the other doesn't. Both hornless parents are heterozygotes.

- Breeding both horned drakes together results in entirely horned offspring. Students who assume that horns must be dominant have no reason to change their thinking from this result.
- Breeding the two hornless drakes together yields some offspring with horns, indicating that horns cannot be dominant.
- Each hornless parent must carry a recessive allele for horns in order for the offspring to inherit that phenotype. If students resist this idea, have them draw the flow of alleles from parent to offspring. This will uncover their thinking so the teacher can decide how to help them move forward.

Claim: A claim should state the answer to the question posed. In this case, horns are recessive.

Evidence: Students should describe experiments supporting the claim, such as breeding two hornless drakes and seeing horned offspring. The Breeding Record URL can be provided as well, but is not a substitute for the description of results.

Reasoning: Students should use the principle that a dominant allele masks the presence of a recessive allele, therefore breeding heterozygotes allows the recessive trait to emerge from two individuals who show the dominant trait. They can also include the principle of independent assortment of chromosomes during meiosis. Students could also point to the numerical aspect of their results if they realize that the 3:1 ratio of hornless to horned drakes represents breeding heterozygotes.

Underlying Genetic Mechanism

The horns trait follows standard Mendelian dominant/recessive inheritance where the hornless allele is dominant to the horns allele.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

D) Case 7: What are the Odds?

The first two challenges of Case 7 draw students' attention to the characteristic proportions of traits in offspring resulting from two types of crosses, homozygous recessive x heterozygous, and heterozygote x heterozygote. These challenges combine pull-down menus and breeding. In previous cases, students have practiced making predictions about offspring phenotypes based on known parental genotypes. They are now asked to reliably produce clutches of drakelings showing specific ratios of traits, demonstrating that they understand the likelihood that certain allele combinations maximize specific outcomes. Use of the stats tab in the breeding pen will be necessary.

The second two challenges introduce crossing over during meiosis. At first students will see that a particular target drakeling is not possible, then they will be able to match the target by selecting alleles to cross over prior to the meiotic divisions. These challenges use the meiosis tool first encountered in Case 2.

There are four activities in this case.

Challenge 1 asks students to submit parents that will result in clutches containing about 50% winged drakes.
Challenge 2 asks students to submit parents that will result in clutches of drakelings containing about 25% wingless, 75% with forelimbs, and 50% that are metallic (steel).
Challenge 3 has students work in small groups to determine whether or not the provided parents are capable of producing a metallic, wingless drakeling. This lays the groundwork for crossover, because the only metallic allele between the two parents occurs on the same chromosome as a wing allele, and crossover will not happen on this screen.
Challenge 4 asks students to create the same metallic, wingless drakeling presented in Challenge 3, but this time they can and must select and cross over one pair of alleles in order to succeed.

Preparing for Case #7

1. Review lesson plan 7A and lesson plan 7B and play through the challenges in this case.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for a large-group discussion.

5. Determine when to supplement Geniverse with a probability lesson.

Considerations for Case #7

1. All students receive the same parents and targets in each challenge.
2. The program awards stars for Challenges 1, 2, and 4, while Challenge 3 requires posting a group answer to the question along with an explanation; evidence is not required. The Demo version of Geniverse cannot access the Journal, so an alternative method will be needed to submit answers to Challenge 3.
3. Challenge 3 cannot be solved because crossover is required and is disabled in this Challenge. In Challenge 4, the ability to cross over is turned on again and the target can be matched.
4. To create the target drakelings without relying on luck, students must think through the possible combinations of the parents' alleles for each trait. They need a way of sorting the allele possibilities, their own or a Punnett square. If the latter has not yet been introduced, now is good time to do so. Help students make connections between Punnett squares and the underlying mechanism of meiosis.
5. Students really only need to understand the Sum Rule and the Product Rule in order to understand the probabilities displayed in Geniverse.
6. Repeated breeding while looking at the stats view will show students that the proportions of offspring with a given trait change with every clutch. At the same time, the program tallies all clutches for the same set of parents.
7. The software creates random combinations of the alleles in each clutch of offspring, so students are seeing realistic fluctuations in the proportions of traits in the offspring. By the end of this activity, students should be getting a feel for the probabilistic nature of independent assortment and for the impact of sample size on probability.
8. This case would be a good place to introduce the idea of dihybrid crosses, but students would need to count drakes. One could also lay the foundation for linkage by having students compare independently sorting genes (like wings and forelimbs) to linked genes (like wings and metallic).

Potential trouble spots

1. Students tend to struggle with the difference between probability of outcomes and the reality. It will be important to work with students to understand that 50/50, 60/40, and 55/45 all qualify as approximately 50/50. (A Chi-square test will indicate that 60/40 is just beyond acceptable, but due to the rounding in the software, it’s best to accept this ratio as sufficiently close to 50/50.)
2. Given known parental genotypes, one can expect that on average certain proportions of traits will appear in the offspring, however the exact proportions vary with each set of offspring and usually approach the average over a larger number of offspring. Students need to breed multiple times before they can feel assured of a statistic.

3. If students seem to be struggling with what the statistics can tell them, it might be helpful to review probability and ratios that result from crossing a variety of heterozygous and homozygous plants or animals outside of Geniverse.
4. In Challenges 3 and 4, students need to pay careful attention to the areas of the chromosome that highlight green when selecting portions to cross over. Their selection must encompass the allele(s) they wish to be included in the crossover, but not the alleles they wish to stay put.
5. Because the target drake in Challenge 3 cannot be matched, students may think they are doing something wrong and might keep trying to solve it, in vain. If this happens, try asking them to explain what they've done so far and why it appears to not be working; this may help them realize that sometimes "no" is the answer.
6. It is often necessary to retry dad's gametes a few times before being able to solve Challenge 4. The recombined chromosome created must also occur with an X chromosome in order to match the given female target. This might frustrate or confuse students who are recombining properly.

Key points

1. A charcoal drake that is also metallic is known as the color "Steel".
2. Breeding parents with certain genotypes, given a dominant/recessive relationship between alleles, results in predictable proportional outcomes in the offspring.

    a. heterozygote x homozyous recessive = 3:1 (dominant:recessive)
    b. heterozygote x heterozygote = 1:1 (dominant:recessive)
    c. Alleles on the same chromosome travel together to the same gamete during meiosis unless a crossover event occurs between them.
    d. Crossover allows for a nearly infinite number of possible gametes, resulting in great variation between siblings of the same parents. This is one reason there are such differences between sets of traits within family trees.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. How close to 50% does "all clutches" need to be to really count as 50%?
2. What evidence is sufficient to "prove" that parent drakes have a certain genotype?
3. Even if the alleles are set "correctly", it is still possible to not get the expected proportions of offspring. Why is this so?
4. What impact does crossover have on the similarities and differences seen within families of blood relatives?

The Answers

1. **Challenge #1:** If one parent's alleles are set wings/no wings and the other at no wings/no wings, then about 50% of their offspring will have wings. This will meet the Duchess's request.
2. **Challenge #2:** Set the parents' alleles as follows to meet the Duke's request:

    a. wings/no wings & wings/no wings *(25% wingless)*
    b. metallic/non-metallic & non-metallic/non-metallic *(50% metallic)*
    c. forelimbs/no forelimbs & forelimbs/no forelimbs *(75% forelimbs)*

3. **Challenge #3:** The mating pair provided cannot produce a metallic, wingless drake, because the only metallic allele in the pair belongs to the father and it shares the same chromosome as a wing allele. Therefore, those two alleles will end up in the same gamete, so all offspring will be metallic with wings, rather than without wings. ***(Note:** Recombination is turned off in this challenge.)*
4. **Challenge #4:** Students need to swap the wings section of one of dad's chromosomes with the no-wings section of its homolog. Then they need to make sure the recombined no-wings/metallic chromosome occurs in a gamete with an X chromosome to match the female target given. Any of the female's eggs will work to solve this challenge.

Underlying Genetic Mechanism

The three traits in Challenges 1 and 2are from Training Level and follow standard Mendelian dominant/recessive inheritance where the metallic, wings, and forelimbs alleles are the dominant ones.

Crossing over, illustrated in Challenge 3, occurs as a necessary part of every meiotic division. It allows for greater variety in gametes by changing the combination of alleles on a chromosome. When an offspring acquires a combination of alleles on a pair of chromosomes for a particular trait that is the same as found in a parent, it is said to have inherited the parental type. When an offspring inherits a different combination of alleles on a pair of chromosomes for that particular trait that differs from that of either parent, it is said to have inherited the recombinant type.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

E) Case 8: A Tale of Three Tails

Case 8 introduces the polyallelic tail trait in drakes for which there are three phenotypes- long, short, and kinked.Students explore this trait initially by choosing alleles but eventually by deducing parental genotypes through breeding. This case includes a meiosis challenge to help students think through the breeding challenges. This case continues to build upon student understanding of

dominant/recessive relationships between alleles, but introduces the concept of an allelic series where there is a “most dominant” allele as well as a “most recessive” allele.
There are three activities in this case.

In the **Playground**, students manipulate tail gene alleles as they have in the past, using pull-down menus, and resulting in an immediate phenotypic change in the drake image presented.

In **Challenge 1**, students use the meiosis tool to select the appropriate parents to match each of the three targets.

In **Challenge 2**, students determine the tail genotype of each of four parent drakes, three female and one male, by breeding them and examining the offspring.

Preparing for Case #8

1. Review the lesson plan for Case #8 and play through the challenges in this case.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine whether or not students will be including an explanation with their answer to Challenge 2.
5. Determine when and how you will convene the class for a large-group discussion.

Considerations for Case #8

1. All students receive the same set of parent and target drakes in each challenge. In Challenge 2, the three female parents all have long tails while the single male parent has a short tail.
2. The program awards stars for the Playground and Challenge 1. Three stars are automatically awarded for doing anything within the Playground activity. Challenge 2 requires each student to post the answer to the question along with an explanation; evidence is not required. The Demo version of Geniverse cannot access the Journal, so an alternative method will be needed to submit answers to Challenge 2.
3. Most genes are polyallelic, and with this case students start to see a more realistic set of genes other than monogenic, strictly dominant/recessive inheritance.
4. Students post their responses to Challenge 2 via the in-software journal, but unlike other times they are told only to indicate the genotype of each of the four parent drakes. The teacher may wish for students to include an explanation of how they made their decisions.
5. Consider having students use Punnett squares to examine patterns that emerge from breeding drakes with various tail genotypes. They could compare these patterns to what they’ve experienced prior to Case #8.

Potential trouble spots

1. Students who skip the Playground activity, are likely to struggle solving these challenges. If students seem to not understand the relationship between the alleles, have them return to the Playground screen to re-explore these relationships.
2. Remind students to pay attention to the sex of the target drakes. They will likely need to retry meiosis several times on the male to get the necessary tail allele to occur with the necessary X or Y chromosome.

Key points

1. There can be more than two alleles of a gene within a population of organisms, but an individual can still only have two alleles for that gene, one from mom and one from dad.
2. Reaffirm that a test cross is a good way to infer unknown genotypes.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. What strategies did you use to determine the genotypes of each female? Why did this/these strategies work?

The Answer

1. There are three alleles involved here in a series of most to least dominant: long > kinked > short.
2. In Challenge 3, the male is short/short, because the “short” allele is the most recessive.

    a. Breeding him to the top left female results in some offspring with long tails (long/short) and others with short tails (short/short), indicating that her genotype is long/short.
    b. Breeding the top right female results in some offspring with long tails (long/short) and others with kinked tails (kinked/short), indicating her genotype is long/kinked.
    c. Breeding the bottom female results in all offspring having long tails (long/short), indicating that her genotype is long/long.

Underlying Genetic Mechanism

Although there can be multiple alleles for a gene within a population, any one organism can only have two alleles for that gene, one obtained from each parent. In the case of tails, there are three alleles that, when paired, follow standard Mendelian dominant/recessive inheritance where long is dominant to either kinked or short, and kinked is dominant only to short.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

F) Case 9: Like Father, Like…

In Case 9 students explore the inheritance of a sex linked trait using the meiosis tool and by breeding. The gene for a nose spike is carried on the X chromosome. Students have been able to see since Training Level that the male's Y chromosome lacks this allele. Using the statistics tab, students can observe unusual patterns for inheritance that differ between males and females. This is the first case where the stable is both present and necessary. Argumentation helps students solidify student understanding.

There are 3 activities in this case.

Using the meiosis tool and breeding in **Challenge 1** students determine whether or not a father drake can pass his nose spike onto his children. Students work in teams to answer this question, then as a group post an argument to the *Journal of Drake Genetics* (DJG+).

Challenge 2 is a target matching activity where students are presented with two parents and four targets. Students need to use the stable in order to successfully complete this challenge.

Challenge 3 students choose from four characters' claims about how nose spike is inherited, then develop and post an argument to support that claim.

Preparing for Case #9

1. Review the lesson plan for Case #9 and play through the challenges in this case.
2. Students post claims for Challenge 1 as a group; determine these groups in advance. Determine whether you want students to work solo or in teams for each of the other two challenges in this case.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Students will need to make use of the chromosome-viewing tool and stable described in the User Guide.
5. Decide in advance whether or not the arguments students generate for Challenges 1 & 3 will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments for Challenge 3 are in the answers section at the end of this case.
6. Determine when and how you will convene the class for a large-group discussion.

Considerations for Case #9

1. All students receive the same parent and/or target drakes in each challenge.
2. Challenges 1 and 3 are argument cases. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised. Challenge 2 is game-like and students earn stars..
3. The answer to Challenge 1 is not as simple as “yes” or “no”. Groups might respond either way in their claim, but it’s the evidence and reasoning they provide that will make their thinking clear to the teacher.
4. Challenge 2 necessitates the use of the stable in order to successfully complete the challenge. Be prepared for some students to find it distasteful to breed drake offspring to each other or back to their parents. If this comes up, explain that it is a common practice in animal breeding for pets and livestock.
5. The chromosome viewing tool is very useful in Challenges 2 & 3.
6. The stats tab in the breeding pen is important in Challenges 2 & 3. Students should notice specific patterns in male and female offspring with respect to the nose spike trait. Students will need to recognize these sex-linked patterns during Journeyman Level when they encounter another such trait.
7. In Challenge 3, breeding a heterozygous female to any male reveals a 1:1 ratio between males with and males without a nose spike. This may need to be pointed out to students, but could be accomplished through questioning.
8. Consider providing students with other opportunities to explore sex-linked traits in the human genome, such as color-blindness and hemophilia.

Potential trouble spots

1. When students cannot produce the male target drake with a nose spike in Challenge 1, you may need to reassure them that "the software is not broken". Have them look carefully at the female phenotype (no nose spike), and examine the four female gametes to assure themselves that none of them carry an allele for nose spike. Guide students to recognize that the drakeling inherits a Y from his father and an X from his mother.
2. Students tend to speak in vague generalities, “Male drakes get their nose spike trait from their mothers and girls get it from their fathers.” Such statements often stem from a particular breeding experiment the student performed. Be prepared to ask students to clarify their thinking by asking questions like:

    a. What breeds did you do that support this statement?
    b. Is this always the case?
    c. What do you predict would happen if you bred these two drakes?
    d. In general, how do males get (or not get) a nose spike?
    e. In general, how do females get (or not get) a nose spike?
    f. In Challenge 3 students are given a female parent without a nose spike and a male parent with a nose spike. Breeding these results in males without nose spikes and females with nose spikes. Although this single breed is enough to eliminate Lucinda’s incorrect claim,

students who stop here will likely choose one of the other incorrect claims by Dale or Tars. Students need to perform additional breeds. One way to help students reach that point is to either suggest additional breeds or to lead them in that direction by asking a question like, “What would happen if you bred... with ...?”

Key Points

1. X-linked traits in females are controlled by two alleles, one received from the mother and the other from the father, each on an X chromosome. In the case of nose spike, the nose spike allele is dominant to the no nose spike allele, so heterozygous females will have nose spikes.
2. X-linked traits in males are controlled by one allele on the X chromosome received from the mother. Males receive a Y chromosome from their fathers and therefore do not receive a second allele for such a trait. So male drakes with a “nose spike” allele on their X chromosome will have a nose spike, while males with a “no nose spike” allele on their X chromosome will not have a nose spike.
3. Male drakes pass on their Y chromosome to their sons and their X chromosome to their daughters. Therefore, males can only pass on X-linked traits to their daughters.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. X-linked recessive diseases and disorders are more common in males than in females. Why is this so?
2. What would it take for a female to inherit an X-linked recessive disease or disorder?
3. What pattern would you expect to see in offspring if an X-linked disease or disorder were dominant?

The Answers

1. In **Challenge 1** only the female target can be made.
2. **Challenge 2**

    a. Breeding the two given parents can only yield two of the targets; the male without a nose spike and the female with a nose spike.
    b. Students need to save an F1 female with a nose spike and an F1 male without a nose spike. Breeding these two together will produce the other two targets most efficiently.
    c. Alternatively, students might back cross a saved F1 female with a nose spike to the father to yield the male target with a nose spike, then back cross a saved F1 male without a nose spike to the mother to yield the female target without a nose spike.

3. **Challenge 3**

Claim: Tamora's is the best: *"The absence of the nose spike is caused by a recessive allele on the X chromosome. Boys only have one X, so the recessive trait is more common in boys."*

Evidence: Students will need to incorporate data from multiple breeds in order to support the correct claim. At least two of these suggested breeds should be done.

- The first breed of the given parents is sufficient to support the X-linked nature of the nose spike. The stats should be included, because they reveal all the females but none of the males from this breed have nose spikes.
- Students can save an F1 female with a nose spike and back cross it to the father (who has a nose spike), resulting in 1:1 ratio of males with and without nose spikes. All of the females will have a nose spike.
- Students can save an F1 male without a nose spike and back cross it to the mother, resulting in all of the offspring not having a nose spike.
- The availability of the chromosome viewing tool allows students to provide evidence beyond breeding. They can indicate whether or not a female with a nose spike is homozygous dominant for the trait, or heterozygous for it.

Reasoning: There are several lines of reasoning students can use in this argument. Their reasoning must justify their choice of evidence.

- Students should have already identified that having a nose spike is the dominant phenotype, so the mother provided in this challenge (without a nose spike) must be homozygous recessive.
- All F1 sons are without nose spikes despite their father having one. Students can compare expected outcomes if this were an autosomal trait, to their observations from this first breed. The results are indicative of an X-linked trait. The father cannot pass the X chromosome with the "nose spike" allele to his sons, so they get a single allele for "no nose spike" from mom, and all the F1 females have nose spikes because the dominant allele is the only one the father had to pass on to his daughters. Students could use Punnett squares to assist them in making this explanation.
- A heterozygous female would produce a 1:1 ratio of sons with and without nose spikes, because there is a 50/50 chance of each gamete containing the dominant or recessive allele. This is another place where Punnett squares would be helpful.
- Crossing two drakes without nose spikes results in none of the offspring having nose spikes. This offers further proof that the nose spike is a recessive trait, because the pattern is similar to other traits examined to date. It does not, however, help establish the X-linked nature of the gene.

Underlying Genetic Mechanism

Nose spike is an X-linked trait that follows the standard dominant/recessive pattern in the diploid state. Therefore, males have one allele for this trait that has sole influence on the phenotype. Females however will show the nose spike phenotype if they are homozygous for the nose spike allele or if they are heterozygous.

The real genes behind these traits

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

G) Case 10: Certification Exam

Case 10 is the final case in the Apprentice level. Once students complete this exam, they are ready to move on to the Journeyman level. The **first Challenge** in this case is much like Case #5. Students combine manipulation of drake genes, breeding, observations of offspring phenotypes, and their understanding of how the traits investigated thus far are inherited. Students are presented with a female drake with seven traits of unknown genotype and a male drake whose alleles for these same seven traits can be manipulated. Students must select the male's alleles so that the offspring will reveal information about the female's genotype.

For the **second Challenge**, students match four randomly generated targets, one at a time. As each is successfully matched, the next is revealed. They accomplish this by manipulating the alleles of both parents using the familiar pull-down menus, then breeding them and looking for a match among the offspring. This challenge is trickier than past target-matching challenges because students are matching 7 traits at a time.

After successfully completing Case 10, the next part of Arrow's story is unlocked, providing yet more information to guide the user in solving for his illness.

Preparing for Case #10

1. Review the lesson plan for Case #10 and play through the challenges in this case.
2. Determine what students should do if they finish the case early.
3. Determine if students will use the relevant handout to record responses in addition to submitting them in the software.
4. Determine how to incorporate the story element that unlocks upon completion of this case.

Considerations for Case #10

1. Each student receives a different, randomly generated female drake of unknown genotype, but with a fixed and defined phenotype, and a male drake whose alleles can be manipulated. If a student retries the activity to earn more stars, they will receive a new female drake. Moves are not counted here. The computer awards stars based on the number of attempts it takes to submit the correct answer.

2. Although it is possible to solve Challenge 1 by trial and error, students that do so will be awarded only a single star. To avoid this, consider requiring that students repeat this challenge until they earn at least two stars.
3. In Challenge 2 each student is presented, one at a time, four randomly generated target drakes. The computer awards stars based on the collective number of moves it takes to match each individual target.
4. For the first time it matters on which chromosome a set of alleles occurs. In earlier target matching challenges, students matched targets for one trait at a time. In Challenge 2 of this Case they are matching for 7 traits at at time, 4 of them are on the same chromosome, recombination occurs, and they need to complete the task in as few moves as possible (meaning minimal allele changes). This will truly test their understanding of meiosis and recombination!

Potential trouble spots

1. If students are still solving Challenge 1 by making the known parent heterozygous for each trait, question them about how it can be solved even more efficiently (ie- setting up a test cross).
2. If students are having difficulty solving for multiple unknown genotypes at once, have them tackle the traits one at a time. As long as they stay logged into this challenge they can switch between the “Lab” and “Ready to Answer” as often as needed until they are ready to “Submit”.
3. If students become frustrated trying to match the targets in Challenge 2, consider gathering the class together to share their thoughts and strategies before returning to the challenge to complete it on their own.
4. For classes with a low frustration threshold, consider projecting Challenge 2 onto a screen and having the class work together to match a target first.

Key points

1. Students should recognize that a test cross is the best way to determine an unknown genotype.
2. Alleles of genes located on the same chromosome end up in the same gamete during meiosis unless a crossover event occurs between one or more of the alleles.
3. Recombination of alleles during meiosis helps explain the great variety observed between members of the same biological family.

Questions for deeper thinking *(Answers will be added as we continue to develop these materials.)*

1. How did recombination impact your ability to solve Challenge 2 in this Case?
2. How does recombination during meiosis affect the similarities and differences observed within families of blood relatives?
3. What patterns did you notice in recombination between pairs of alleles on any of the chromosomes? What might explain these patterns?

Underlying Genetic Mechanism

- Metallic, wings, horns, forelimbs and hindlimbs follow standard Mendelian dominant/recessive inheritance where the metallic, wings, hornless, forelimbs, and hindlimbs alleles are dominant.
- For tails there are three alleles involved in a series of most to least dominant: long > kinked > short.
- Nose spike is an X-linked trait that follows the standard dominant/recessive pattern in the diploid state. Therefore, males have one allele for this trait that has sole influence on the phenotype. Females however will show the nose spike phenotype if they are homozygous for the nose spike allele or if they are heterozygous.

The real genes behind these traits

All drake traits are based on genes from real organisms like mice and anole lizards. Stay tuned for this information as we continue to build these materials.

Journeyman Level Teacher Guide

A) Overview

Journeyman Level assumes that students are comfortable with basic inheritance concepts regarding genotype-phenotype relationships, dominance and recessiveness, multiple alleles, sex-linked inheritance, independent assortment in meiosis, test crosses, probability, and the process of argumentation. There are no more pull-down menus in this level; students investigate new traits through breeding experiments alone. They must apply their knowledge of the above concepts to determine whether an inheritance pattern fits an old scheme or if a new one is represented. Their ability to support their claims about modes of inheritance should start to become more practiced and require less support.
Students will encounter incomplete dominance in the armor trait, where the number of plates of armor on the drake are incremental. They will also encounter the multigenic nature of drake color.

<u>Items unlocked in this level</u>:

- The Journeyman Level of the Gene-to-Protein Genie (after Case 14)
- The third cartoon panel in Arrow's continued story (after Case 15)

Five cases comprise the Journeyman level:

Case #11, Feelin' Hot, Hot, Hot..., contains two argumentation activities
Case #12, The Right to Bear Armor, contains one argumentation activity
Case #13, All for One and One for All, contains four target-matching challenges
Case #14, Color My Drake, contains a sequence of three challenges requiring a group claim and an individual claim
Case #15, is a Certification Exam composed of a single target-matching challenge

B) Learning Goals

The following learning goals are addressed by the end of the Journeyman Level:

Students will know that..

1. For some traits primarily influenced by a single gene, some alleles are dominant to others. A dominant allele will completely mask the presence of the recessive allele in external phenotype.
2. Specific combinations of parents' alleles result in characteristic patterns in the proportions of offspring.
3. Genes exist in different forms called alleles. There are usually more than two alleles for a gene, resulting in more than two phenotypes.
4. Some traits show patterns of inheritance that follow the inheritance of sex chromosomes because those genes are on a sex chromosome.
5. For some traits primarily influenced by a single gene, both alleles will have some effect, with neither being completely dominant.
6. There are traits that result from a single gene and others that result from the interaction between multiple genes.

Students will be able to…

1. Predict possible genotypes for an organism based on its phenotype.
2. Use numerical patterns in the phenotypes of the offspring to determine the genotype of the parents.
3. Predict an organism's phenotype based on its genotype.
4. Use parental genotypes to predict the set of offspring phenotypes and their approximate proportions.
5. Use a test cross to determine unknown genotypes.

C) Case 11: Feelin' Hot, Hot, Hot

Case 11 introduces the polygenic nature of drake color by introducing two new colors- lava and copper. Students investigate these new colors through breeding experiments. They build upon their prior understanding about the relationship between the colors charcoal and steel, and upon their knowledge about the role of the metallic gene, which they've seen since Training level. This case also requires students to continue building their argumentation skills by posting two claims about the inheritance of color in drakes, the second building upon the first. This approach introduces the concept that explanations are revised as new evidence is uncovered. Students will return to further refine their explanations about color inheritance in Case 14.

There are two challenges in this case.

In **Challenge 1** students investigate the relationship between the colors lava and charcoal by performing breeding experiments. They submit a claim explaining the inheritance of color.

Challenge 2 asks students to refine and resubmit their explanation about the inheritance of color based on further explorations that include the addition of the color Copper.

Preparing for Case #11:

1. Review the sample lesson plan for Case #11 and work through the challenge.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for a large-group discussion.
5. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.

Considerations for Case #11:

1. All students receive the same parents at the start of each challenge.
2. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ button). The Journal is not available through the Demo version, so an alternative method will need to be devised.
3. Students should save F1 offspring and intercross them as well as backcrossing them to the parents.
4. The data available in the stats tab is critical to solving the challenges. See the User Guide for more information about this feature.
5. Challenge 2 really represents a dihybrid cross. Unfortunately the stats tab is unable to represent dihybrid statistics. Also, the two genes at play here affect the same trait (color), which is an unusual approach to dihybrids. Consider introducing dihybrids prior to this case.

    a. The Case 7, Challenge 1 screen with pull-down menus and the ability to breed, could be used to examine two unrelated drake traits, like wings and forelimbs, although students would have to count drakes with each combination of phenotypes.
    b. Non-Geniverse examples would also be useful.
    c. This case is a good place to introduce the Chi-square test, if students are capable of doing the calculations and/or understanding the results. Online Chi-square calculators

like this one may be useful to teachers who would like to use Chi-square tests without focusing on the calculations as much.

Potential trouble spots:

1. Students who do not plan and keep careful record of their breeding experiments and results are likely to become frustrated trying to solve these challenges.

    a. If you don't use the handouts provided, consider providing another structured means of planning and recording the results from experiments.
    b. While interacting with students as they work, question them as to what drakes they bred, what results they got for a particular breed, and what the data might imply. Then encourage them to summarize in writing what they just told you.
    c. Thus far, every trait has been controlled by a single gene. If students come to think of each color as a separate entity, they may try to assign one gene to each color, even though the evidence won't support this. Even students familiar with dihybrid crosses are unlikely to notice the dihybrid nature of the four colors presented in Challenge 2. They may need help seeing that
        i. There are metallic/non-metallic color pairs: copper/lava and steel/charcoal.
        ii. There are "opposing" colors: lava/charcoal, as well as their shiny versions, copper/steel. Lava & copper have an orange base while charcoal & steel have a black/gray base.
        iii. Consider asking students to describe the relationship between the two colors with which they are most familiar, charcoal & steel (steel is a charcoal drake with at least one Metallic allele). Using a projected image of the Case 7, Challenge 1 screen might be helpful.
        iv. Students could then be asked to explain whether or not there is a similar relationship between lava & copper.
        v. If students are having difficulty establishing that there are two genes at work in Challenge 2, try asking something like, "How many phenotypes are possible from one gene?". The typical one gene, two allele model can only yield 2-3 phenotypes. Although multiple alleles for a gene can produce more than two phenotypes within the population, Punnett squares will quickly show that is not the case here.

Key points:

1. There are two genes at work here, the already familiar Metallic gene and a second gene that controls whether or not a drake is Charcoal or Lava.
2. Steel and Copper are "metallic" versions of Charcoal and Lava.

Questions for deeper thinking: (Answers will be added as we continue to develop these materials.)

1. How can we estimate the number of genes and alleles that might be influencing a particular trait?
2. How do we know how many genes are involved in developing the four drake colors observed in Case 11?
3. Which breeding experiments were most helpful in solving Challenge 1 (or Challenge 2) and why?

The Answers:

1. Challenge 1 helps students establish that Charcoal is dominant to Lava. This is an oversimplification, but is the best description at this point. Students will refine this explanation in Case #14.

    a. Claim- Charcoal is dominant to Lava
    b. Evidence will include the patterns found in the data from one or more breeding experiments. The Breeding Record URL can be provided as well, but is not a substitute for the description of results. A complete set of data will include the following breeding experiments:

    i. Lava x Charcoal yields 50/50 Lava:Charcoal
    ii. Lava x Lava yields 100% Lava
    iii. Charcoal x Charcoal yields 75/25 Charcoal:Lava
    iv. Reasoning may include the following:

    - Students should include an explanation of how each statistic is indicative of breeding a particular pair of genotypes. One way to do this is to use Punnett squares to help explain the results of their breeding experiments.
    - At a more advanced level, students might include Punnett squares that illustrate why the genotypes cannot be other than what they've suggested (counterargument).
    - Students should also refer to the principle that a dominant allele masks the presence of a recessive allele, therefore breeding heterozygotes allows the recessive trait to emerge from two individuals who show the dominant trait. At this level they should also point to the numerical aspect of their results, realizing that the 3:1 ratio of charcoal to lava represents breeding heterozygotes.

    Challenge 2:

- Claim: Students may say something like, "There are two genes controlling color," or "One gene makes the drake charcoal or lava and another gene makes it metallic or not (shiny or not, steel or copper)."
- Evidence: Will come from a variety of breeding experiments and should indicate what drakes were bred and what the results of the breeds were. Evidence for the autosomal

nature of what makes drakes shiny comes from any breed to a shiny (metallic) drake. In every case, the offspring will include metallic drakes of both sexes.

- Reasoning: Should explain what the breed results indicate and why. Again, Punnett squares help to make such explanations. Students capable of performing Chi-square tests can use that data as part of their reasoning as well. Students should also refer to their knowledge of dominant/recessive traits.

Note: If students combine evidence and reasoning in the same part of the scaffold, this is less of a problem than if they exclude evidence and/or reasoning entirely. The teacher will need to determine, based on his/her own setting, how important it is for students to clearly separate these two.

Underlying Genetic Mechanism:

Students are observing the interaction between two autosomal genes.

1. The *Metallic* gene, with which they are already familiar, controlling whether or not the drake is shiny.
2. The *Brown* gene controls whether or not the drake has a gray/black base color or an orange/yellow base color. The black color (B) is dominant to the orange color (b). Any letter notation could be used, the letter b is used here by convention (see The Real Genes Behind These Traits below).
3. The genotypes of the parents are provided below

   a. Challenge 1
      i. Lava female = mm bb
      ii. Charcoal male = mm Bb

   b. Challenge 2

      i. Lava female = mm bb
      ii. Steel female = MM Bb
      iii. Charcoal male = mm Bb
      iv. Copper male = MM bb

The real genes behind these traits:

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

D) Case 12: The Right to Bear Armor

The single Challenge in Case 12 revisits the framework for scientific argumentation and introduces students to a new trait- armor. Drakes can have 0, 3, or 5 armor plates. This case extends students' conceptions of allele interactions by introducing an interaction where one allele is incompletely dominant to another.

Students are presented with a breeding screen and two parents, each with 3 armor plates. They must breed the parents as well as F1 offspring, and examine the results in order to answer the question: "How is armor inherited?" The challenge culminates with students posting a claim, supported by evidence and reasoning, in the Journal of Drake Genetics.

Preparing for Case #12:

1. Review the sample lesson plan for Case #12 and work through the challenge.
2. Determine when students should work solo and when they should work with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for a large-group discussion.
5. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.

Considerations for Case #12:

1. All students receive the same two parents, each with 3 armor plates.
2. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised.
3. Students should save F1 offspring and intercross them as well as backcrossing them to the parents.
4. The data available in the stats tab is critical to solving this challenge. See the User Guide for more information about this feature.
5. Encourage students to develop and track an organized breeding strategy. The goal is to breed all possible combinations of armor. They can use the provided handout to keep track of their work.
6. Help students recall what they already know about the inheritance mechanisms and genotypes of other traits, and how they can represent these using letter combinations (e.g. Aa).
7. As students form ideas about how inheritance of armor works, encourage them to test each idea as it arises by performing the necessary breed(s) and recording the results.
8. Encourage students to use Punnett squares to make predictions and check their predictions.
9. Be prepared with some probing questions to ask individuals, groups or the class. Some of these might include:

a. How does this trait seem to compare to those we've already seen?
b. How might you represent the alleles for this trait?
c. What patterns emerge in the data when you breed ___ plates with ___ plates?
d. What have you learned or think you've learned from the breeds you've already done?
e. Which breed provides the most useful information and why?
f. What is the evidence that this is/is not a dominant/recessive trait?
g. If it's not dominant recessive, what are some other possibilities given that any organism can only have two alleles for a gene?
h. How many genes seem to be involved and what is your evidence?
i. How many alleles seem to be involved and what is your evidence?
j. If most of the class seems stuck, it might be helpful to bring them together to share their ideas using some of the questions suggested above. Recording student ideas in a visible place to which they can refer later may prove useful to them.
k. Co-dominance is not part of Geniverse. If this is an important part of the curriculum, consider introducing it after this case is concluded.

Potential trouble spots:

1. Students who do not keep accurate records of their breeding experiments will probably become frustrated. If the provided handouts are not used, students will need another means of organizing and recording breeds and their results.
2. Students may not breed all possible combinations of armor. Encourage them to do so or to explain why they feel it is not necessary to do so.
3. Students can become adept at "filling in" Punnett squares without truly understanding the mechanisms they are meant to help illustrate. Prompt students to provide an explanation, along with a Punnett square, that makes clear their understanding of the relationship between the alleles, and the connection to meiosis.

Key points:

1. Not all traits result from a simple dominant/recessive interaction between alleles. In fact, most traits do not work that way.
2. Three armor plates result from an incompletely dominant relationship between an allele that produces 5 plates in a homozygous condition and one that produces 0 plates in a homozygous condition.
3. Three phenotypes can result from two alleles, when one is incompletely dominant to the other.

Questions for deeper thinking: (Answers will be added as we continue to develop these materials.)

1. What breed or combination of breeds provided the best data for solving this problem? Why?

2. How can we use the number of possible phenotypes for a trait to help us figure out the inheritance mechanism for the trait?

The Answer:

Claim: This should be a statement about how plates are inherited. For example, students with the vocabulary might state, “Armor is incompletely dominant.” Others might say something like, “5 plates is AA, 3 plates is Aa, and 0 plates is aa.”, or “heterozygotes have 3 plates, one homozygote has 5 plates and the other homozygote has 0.”

Evidence: Students should describe experiments supporting the claim. The most telling breed is between two drakes each with 3 plates, which results in offspring with 0, 3, and 5 plates. The Breeding Record URL can be provided as well, but is not a substitute for the description of results. This single breeding experiment would not be sufficient data to support a claim, but it is at least appropriate. What the teacher deems “sufficient” for his/her students may vary with the abilities of the students and their prior experience with using evidence to support claims.

Reasoning: Students can use the principle (in their own words) that when one allele is incompletely dominant to another the heterozygotes display a phenotype somewhere between both homozygous conditions. They can also include the principle of independent assortment. Students could also point to the numerical aspect of their results. For example, the 1:2:1 phenotypic ratio of offspring from a 3-plate x 3-plate cross mirrors the genotypic ratio (homozygous dominant: heterozygous: homozygous recessive). In a dominant/recessive relationship, the 1:2:1 genotypic ratio would show a 3:1 phenotypic ratio, with heterozygotes displaying the same phenotype as the homozygous dominant organisms.

The most advanced arguments will include breeding results from all possible crosses, and will explain them in the reasoning section.

Note: If students combine evidence and reasoning in the same part of the scaffold, this is less of a problem than if they exclude evidence and/or reasoning entirely. The teacher will need to determine, based on his/her own setting, how important it is for students to clearly separate these two.

Underlying Genetic Mechanism:

Students are witnessing the results of an incompletely dominant relationship between two armor alleles in the heterozygous condition. The software uses “A_1” to represent the 5-plate allele, and “a” to represent the 0-plate allele. This notation is not visible through the chromosome viewing tool until Case #13. The following allele combinations account for the plate numbers observed in this case:

5 plates = A_1A_1
3 plates = A_1a

0 plates = aa

Armor is revisited in Case 16 of the Master Level where another plate phenotype is introduced and determining the genetic mechanism is more challenging.

The real genes behind these traits:

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

E) Case 13: All for One and One for All!

This is a target-matching case that involves all traits investigated to date, except metallic and color (all drakes are charcoal). Students need to breed for multiple traits simultaneously. This case provides students with the opportunity to solidify their understanding about inheritance patterns and about the role of meiosis in the inheritance of traits. Careful planning before breeding and keeping accurate records of one's work are critical elements for successfully solving the four challenges. This case is as much about problem solving as it is about content.

In Challenges 1-3, students match a single target each time. All students receive the same parent and target drakes.

In Challenge 4, students need to create a breeding pair of drakes capable of producing all three offspring, although not in one clutch. All students receive the same parents and three target drakes.

Preparing for Case #13:

1. Review the sample lesson plan for Case #13 and work through the challenge.
2. Determine if students should work solo or with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for a large-group discussion.
   Considerations for Case #13:
1. All students receive the same parents and targets in each challenge.
2. In Challenge 4, students should save the matched targets in the stable.
3. Before beginning this case, consider reviewing the inheritance of each trait and the connections between meiosis, including crossover, and inheritance.
4. The stable can hold a maximum of 10 drakes. Students will need to delete intermediate drakes when they are no longer needed in order to make room for new intermediates.
5. Remind students about the predictive power of Punnett squares, or whatever mechanism they use to trace the flow of genes from one generation to the next.
6. The genotype for any drake, except the targets, is visible using the chromosome-viewing tool.

7. This type of case could be completed out of class.

Potential trouble spots:

1. The most likely issue will be student frustration. Challenges 3 and 4 are particularly difficult. Here are some tips for helping students move past the frustration:

    a. Consider having the class work together to match the target in Challenge 1.
    b. Stress the importance of developing a breeding plan before starting to breed. Give them an opportunity to practice this with the target in Challenge 1, guiding them as needed. If time permits, have students share their successful breeding strategies.
    c. Consider letting students collaborate on problem-solving for the rest of the challenges.
    d. All four challenges, but especially Challenge 4, require multiple breeding steps to complete. Here are some tips for guiding students in developing breeding plans.

        i. One trait at a time, have students decide what the genotype(s) could be for each target offspring. This can be used to determine what the genotype of each parent would need to be in order to produce each of the targets for that trait.
        ii. Then students need to “make” those parents.

            - Start by breeding from the parent pool. Save offspring to the stable and use them to continue the breeding process.
            - Remind students to use the magnifying tool.
            - Suggest breeding for one trait at a time, or for two traits on the same chromosome. Students should save the intermediate drakes that breed true for these first traits, then use them to breed for the next trait(s) they wish to tackle.
            - Help students identify when crossing over may be required in order to achieve a target with a certain combination of traits. Some alleles cross over more frequently (eg- wings and metallic) than others (eg- forelimbs and hind limbs).

Key points:

1. Scientists keep detailed records of their experiments in order to recall how they arrived at their end product, so that they and others can repeat them when necessary, and to use as evidence to support conclusions.
2. One can infer genotypes of organisms through breeding experiments.

Questions for deeper thinking: (Answers will be added as we continue to develop these materials.)

1. What are some key elements of a breeding plan designed to generate offspring with a specific set of phenotypes?
2. In what ways does crossover impact the flow of genes from one generation to the next?

Underlying Genetic Mechanism:

No new genes were introduced during this case. The mechanisms for the set of traits available to this point have been previously described in Case 1 of the Training Level Teacher Guide, in Cases 6, 8, and 9 of the Apprentice Level Teacher Guide, and in the Case 11 and 12 sections of this guide.

The real genes behind these traits:

No new traits were introduced during this case. The real genes behind the set of traits available to this point have been previously described in Case 1 of the Training Level Teacher Guide, in Cases 6, 8, and 9 of the Apprentice Level Teacher Guide, and in the Case 11 and 12 sections of this guide.

F) Case 14: Color My Drake

Case #14 reveals four more drake colors. The sequence of challenges in this case allows students to uncover the rest of the inheritance mechanism behind the polygenic trait of color, and to integrate all aspects of color they have learned. Collaboration between group members is essential in this case, because no one student has all the necessary drakes for solving the problem.

There are three challenges in this case.

In Challenge #1 students figure out how two new colors, ash and sand, fit into color inheritance. Half the group members explore each color variation and come together to discuss and update their understanding of color inheritance in drakes given this new information.

Challenge #2 introduces silver and gold, requiring students to again update their explanation of color inheritance in drakes. Again, half the group members explore each color variation and then come together to reach consensus about the larger picture of color. A group claim is posted.

Challenge #3 is the final argument challenge in Journeyman. Students can finally generate and interbreed drakes of all colors. This allows them to check ideas about color inheritance that arose in the first two challenges, before posting individual claims to the Journal of Drake Genetics.

Preparing for Case #14:

1. Review the sample lesson plan for Case #14 and work through the challenge.

2. Create student groups and determine which group members will be “member 1” and which will be “member 2” for Challenges 1 and 2. (The lava/sand and lava/copper/sand combinations are the easier ones to solve.)
3. Have a plan for what groups should do if they finish before others.
4. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
5. Determine when and how you will convene the class for large-group discussions.
6. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.

Considerations for Case #14:

1. Collaboration is required during the first two challenges. See the User Guide for an explanation of how to have students change their group member number.
2. All students receive the same parents at the start of each challenge.

    a. In Challenge 1, Member 1 receives ash/charcoal, while Member 2 receives sand/lava (easier to solve).
    b. In Challenge 2, Member 1 receives copper/lava/sand (easier to solve), while Member 2 receives steel/charcoal/ash. [This is essentially the reverse of Challenge 1, allowing students to see each color before Challenge 3.]
    c. In Challenge 3, all students receive the same two charcoal female parents and steel male parent.
    d. In Challenges 1 and 2, students see the impact of only two of the three color genes, (a) Metallic, and (b) the one that makes drakes a deeper vs. a lighter shade of that color (charcoal vs. ash or lava vs. sand). This will be reflected in their claims for Challenge 2.
    e. Challenge 3 is the first time individual students can interbreed drakes from the black/gray and orange/yellow color bases and witness the impact of all three color genes. Although groups have already discussed their color sets with each other, students will likely need to share their ideas again before formalizing them into the individual posts required for the Journal of Drake Genetics.
    f. In all challenges, students should save F1 offspring and intercross them. Backcrossing them to the parents can also be informative.
    g. Encourage students to take careful notes as they breed; the pedigree of drakes can be important. These notes can serve as evidence for claims.
        i. Students should breed any pair of drakes 3-5 times before examining the data for patterns. The stats tab is critical to solving these three challenges.
        ii. Encourage students to plan their breeds and to predict before breeding. Encourage them to use Punnett squares as a tool to make and check these predictions.

iii. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised.

iv. The chromosome viewing tool reveals the traits learned in Training and Apprentice levels plus armor. Challenge #3 removes Metallic from view.

v. Both teacher and student may find the following probing questions helpful as they interact with each other during this case:

- How do you know?
- What's your evidence?
- How can you find out…?
- What would you expect if you…?
- What evidence do we have that there is a certain number of alleles at work here?
- What evidence do we have that there is a certain number of genes at work here?

vi. The process of developing explanations based on evidence and trying to convince others using this evidence, could be considered more important than getting the "right answer". Students may hover on the edge of understanding the complete color mechanism; they may understand pieces of the puzzle but not the whole picture. The teacher can help students recall and use what they have already learned as they work to solve this case. The answer can always be given at the end, but it doesn't have to be. When color inheritance in mice (on which drake color is based) was first worked out, there were no answer keys.

vii. Chi-squared tests can be helpful in confirming hypotheses about mechanisms related to color inheritance. Students need not perform the calculations themselves as there are a number of online calculators that will do the math for them. Students only need to learn about the purpose of such a test and how to interpret the results.

Potential trouble spots:

1. Frustration is one of the most likely difficulties students will face.

    a. Providing time and a structured means to discuss ideas with peers will help students develop their understanding and should help keep the frustration to a minimum.
    b. Help students recall the inheritance patterns they've already learned about in Geniverse and encourage them to compare those to what they see in the Case #14

Challenges. If necessary, students can return to earlier challenges to review one or more of these traits' stats.

c. Rushing through breeding without a plan or well kept records will lead to frustration. Encourage students to predict outcomes before breeding two drakes, and to consider what information the results might provide. Also encourage them to record these predictions, results and what was learned from that data.
d. Students tend to think of one color as being dominant or recessive to another color and will likely be tempted to try to develop a hierarchy of dominance amongst the colors. They also tend to think of each color as a separate entity, which impedes their ability to consider multiple genes interacting to generate the colors.
    i. As students start to form ideas about how their new colors are inherited, prompt them to illustrate their ideas using Punnett squares.
    ii. Help students sort the colors into groups in order to see patterns that can help them envision multiple genes at work.

        - There are shiny drakes (steel, copper, silver, gold) and there are non-shiny drakes (charcoal, lava, ash, sand).
        - There are black/gray drakes (charcoal, steel, ash, silver) and there are orange/yellow drakes (lava, copper, sand, gold).
        - There are deep/light colored pairs of drakes (charcoal/dust, steel/argent, lava/sand, copper/gold).

Key points:

1. This Case reveals the final color gene called "dilute", that controls how deep or light the color is (charcoal vs. ash and lava vs. sand). It is on the X chromosome.
2. The color trait has 8 phenotypes and is controlled by three genes, each with two alleles. One gene controls whether or not a drake is shiny, another controls whether a drake's color base is gray/black or orange/yellow, and the third controls how deep the color is.

Questions for deeper thinking: (Answers will be added as we continue to develop these materials.)

1. Compare the number of phenotypes possible from each inheritance pattern we've learned about thus far.
2. What pair of drakes (by genotype) would be capable of producing all possible colors in both sexes?

The Answer:

1. In Challenge 1:

a. Students should recognize that something about ash is recessive to charcoal, and that something about sand is recessive to lava.
b. Students should be able to sort drake colors into deep/dark vs. light (charcoal & lava vs. ash & sand).
c. The parental breed that Member 1 performs first results in a 50:50 ratio of charcoal to ash.
    i. Initially students might consider that a heterozygote was bred to a homozygous recessive individual as the stats match this scenario. Breeding two F1 charcoal drakes will not support this conclusion because

        - It results in a 75:25 ratio of charcoal to ash, and
        - All of the ash drakes are male. The zero under the females is the tell-tale sign of X-linkage.

d. The parental breed that Member 2 performs first results in 50:50 ratio of lava to sand, but all the lava drakes are female while all the sand drakes are male.
    i. This is the classic X-linked data pattern, but students need to perform additional breeds to determine how this works in females of the heterozygous condition.
    ii. Backcrossing a saved F1 lava female to the lava male parent results in 75:25 ratio of lava to sand offspring where all the sand drakes are male.

        0. The appearance of sand from two lava parents indicates there is something recessive about sand.
        1. Having all male sand drakes reinforces the X-linked nature of some aspect of sand (sand itself is not X-linked; seePotential Trouble Spots #2).

2. **In Challenge 2:** Students are still working with only one set of colors, either charcoal/ash and their metallic versions (steel/silver), or lava/sand and their metallic versions (copper/gold). If they didn't pick up on it in Challenge 1, by now students should recognize that each metallic color has a non-metallic partner (copper/lava, silver/ash, gold/sand), just like the steel/charcoal pair seen since Training Level.

a. Claim: Students should somehow identify that there are two genes causing the colors they were investigating, that one of them is X-linked, and that in the heterozygous condition one allele is dominant to the other. [Note: Because they have not yet been able to interbreed drakes from the gray/black and orange/yellow color bases, they will not be able to make claims about potential interactions between these; that comes in the next challenge.]
b. Evidence: There are many breeding experiments students might submit as evidence. Here are some examples.
    i. When two non-shiny drakes are bred, all offspring are non-shiny.

ii. Any crosses like those from the In Challenge 1 section above.

iii. F1 intercrosses of any shiny drakes (steel, silver, copper, gold) result in a 75:25 ratio of the shiny colors to the non-shiny colors (charcoal, ash, lava, and sand) spread across both sexes.

- To “see” this ratio, one must total all shiny drakes in a clutch, and also tally all non-shiny drakes in a clutch when, more than two colors appear in the stats tab.
- F1 intercrosses of copper drakes or of steel drakes each results in offspring of four different colors. The stats for these can be examined in a couple of ways:
  - Shiny vs. non-shiny
    - copper + gold vs. lava + sand
    - steel + silver vs. charcoal + ash
  - Deep/dark colors vs. lighter colors
    - copper + lava vs. gold + sand
    - steel + charcoal vs. silver + ash

c. Reasoning: Because there are two genes involved for each color set, student reasoning should be more extensive than in prior cases where only one gene was involved. Students should provide an explanation for the results of each breed they submit as evidence, clearly connecting each piece of evidence to a particular part of their claim. Working from Punnett squares used to make and test predictions about breeding results makes this easier to do. Students should be able to incorporate principles of meiosis (each parent contributes one allele to an offspring through the egg or sperm), with the interactions between the alleles in the offspring (dominant/recessive and X-linked apply here).

3. **In Challenge 3:** This is the first time students have been able to interbreed the gray/black and orange/yellow color bases, bringing all three genes into play at once.

a. Claim: There are three genes controlling drake color. One makes them shiny, another makes them black/gray or orange/yellow, and another makes them darker or lighter colored. The genotype for each drake color follows:

i. Steel: M* B* X^DX^* or X^DY
ii. Charcoal: mm B* X^DX^* or X^DY
iii. Copper: M* bb X^DX^* or X^DY
iv. Lava: mm bb X^DX^* or X^DY
v. Silver: M* B* X^dX^d or X^dY
vi. Ash: mm B* X^dX^d or X^dY
vii. Gold: M* bb X^dX^d or X^dY
viii. Sand: mm bb X^dX^d or X^dY

b. Evidence: Students will present as evidence any combination of breeding experiments and their breeding link URLs. Their explanation of how each set of results supports one or more parts of their claim should be addressed in the Reasoning section.
c. Reasoning: Students should take the approach of explaining how their evidence supports their conclusions about the role of each gene in the color of drakes. Punnett squares that make and test predictions about allele interactions will still be useful in explaining this and also in supporting their choice of genotype for each color. Students should also still cite principles of meiosis.

Note: Student notations may vary; what's presented above is convention based on the real genes behind color. For those less familiar with the conventions of genetic notation, an * indicates that either the dominant or recessive allele can be paired with the first for the same phenotype. E.g.- Mm or MM both result in shiny drakes.

Underlying Genetic Mechanism:

1. Metallic is an autosomal gene following a dominant/recessive inheritance pattern, where mm results in non-shiny drakes (charcoal, ash, lava, sand), while M* results in shiny drakes (steel, silver, copper, gold).
2. Brown is an autosomal gene also following a dominant/recessive inheritance pattern, where bb results in orange/yellow drakes (lava, copper, sand, gold) and B* in black/gray drakes (charcoal, steel, ash, silver).
3. Dilute is an X-linked gene following a dominant/recessive inheritance pattern in the heterozygous condition, where X^dX^d or X^dY result in light-colored drakes (ash, silver, sand, gold) and X^DX^* or X^DY result in deep-colored drakes (charcoal, steel, lava, copper).

The real genes behind these traits:

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

G) Case 15: Certification Exam

Case 15 is the final case in the Journeyman level. Once students complete this exam, they are ready to move on to the Master level. The Journeyman Certification Exam consists of a single challenge where students must breed from a pool of three parents to match four targets. The targets do not have to be met by one breeding pair. Each student starts with the same set of parents and receives a set of four targets, two of which are the same for all while the other two may vary.

The computer awards 1-3 stars based on the number of total, combined moves it takes to match all four targets. Students who complete the task in 30 or fewer moves receive 3 stars.

After successfully completing Case 15, the third cartoon panel in Arrow's story is unlocked.

Preparing for Case #15:

1. Review the sample lesson plan for Case #15 and work through the challenge.
2. Have a plan for what students should do if they finish before others.
3. Determine if students will use the relevant handout to record responses in addition to submitting them in the software.
4. Determine how to incorporate the story element that unlocks upon completion of this case.

Considerations for Case #15:

1. Each student receives an identical set of parents- two charcoal females and one charcoal male.

    a. All three parents are heterozygous for the black/orange gene.
    b. Both females are heterozygous for the dilute gene.
    c. The male has the dominant dilute allele.
    d. Each student receives the same 2nd and 4th target drakes. The 1st and 3rd targets may vary between students, but only in their color.
    e. The chromosome viewing tool will reveal the alleles for: tail, metallic, wings, horns, forelimbs, hindlimbs, and nose spike. Students need to use patterns in offspring to infer genotypes for the black/orange gene, the dilute gene, and the armor gene.
    f. Using the chromosome viewing tool is necessary for successful completion of this case.

Potential trouble spots

1. If students become frustrated trying to match the targets, consider gathering the class together to share their thoughts and strategies before returning to the challenge to complete it on their own.
2. For classes with a low frustration threshold, consider projecting the challenge onto a screen and having the class work together to match one of the common targets first (2nd or 4th).
3. Like Case #13, matching each target requires multiple breeding steps. Remind students of the need to develop a plan before they start breeding. Refer to the Potential Trouble Spots section of Case #13 for more suggestions to help students navigate this task.

Key points

1. Scientists keep detailed records of their experiments in order to recall how they arrived at their end product, so that they and others can repeat them when necessary, and to be used as evidence to support conclusions.
2. One can infer genotypes of organisms through breeding experiments.

Questions for deeper thinking: (Answers will be added as we continue to develop these materials.)

1. Describe the steps you took to match each target.

Underlying Genetic Mechanism

No new genes were introduced during this case. The mechanisms for the set of traits available to this point have been previously described in Case 1 of the Training Level Teacher Guide, in Cases 6, 8, and 9 of the Apprentice Level Teacher Guide, and in the Case 11 and 12 sections of this guide.

The real genes behind these traits

No new traits were introduced during this case. The real genes behind the set of traits available to this point have been previously described in Case 1 of the Training Level Teacher Guide, in Cases 6, 8, and 9 of the Apprentice Level Teacher Guide, and in the Case 11 and 12 sections of this guide.

Master Level Teacher Guide

A) Overview

Master Level is challenging! It also contains interesting new traits, and the conclusion to Arrow's story. This level, like the last, assumes that students are comfortable with basic inheritance concepts regarding genotype-phenotype relationships, dominance and recessiveness, multiple alleles, sex-linked inheritance, independent assortment in meiosis, test crosses, probability, the process of argumentation, and add to that an understanding of polygenic traits. There are still no pull-down menus, and students continue to investigate new traits through breeding experiments. They must apply their knowledge of the above concepts to determine whether an inheritance pattern fits an old scheme or if a new one is represented. Their ability to support their claims about modes of inheritance should start to become more practiced and require less support.

<u>Items unlocked in this level</u>:

- The fourth cartoon panel in Arrow's continuing story (after Case 17)
- Case 18: Bog Breath (after Case 17)
- The Bog Breath Level of the Gene-to-Protein Genie (after Case 18)
- The final cartoon panel of Arrow's story (after the Bog Breath Level Gene-to-Protein Genie)

Three cases comprise the Master level:

Case #16, *Full Armor Jacket*, consists of one argumentation activity
Case #17, *Frosty's Fate*, consists of one argumentation activity
Case #18, *Bog Breath*, consists of one argumentation activity

B) Learning Goals

The following learning goals are addressed by the end of the Master Level:

Students will know that..

1. Genes exist in different forms called alleles. There are usually more than two alleles for a gene, resulting in more than two phenotypes.
2. For some traits primarily influenced by a single gene, some alleles are dominant to others. A dominant allele will mask the presence of the recessive allele in external phenotype.
3. For some traits primarily influenced by a single gene, both alleles will have some effect, with neither being completely dominant.
4. Specific combinations of parents' alleles result in characteristic patterns in the proportions of offspring.

Students will be able to…

1. Predict possible genotypes for an organism based on its phenotype.
2. Predict an organism's phenotype based on its genotype.
3. Use parental genotypes to predict the set of offspring phenotypes and their approximate proportions.
4. Use the numerical patterns in the phenotypes of the offspring to determine the genotype of the parent(s).

C) Case 16: Full Armor Jacket

The **single Challenge** in Case 16 reveals a new armor phenotype- a single armor plate. Now drakes can have 0, 1, 3, or 5 plates, and students must figure out how to incorporate this new phenotype into their existing knowledge of how the armor trait works. This challenge combines the incomplete dominance observed in Case #12, with the idea of multiple alleles experienced in Case #8, and with the now familiar concept of dominance/recessiveness.

Students are presented with a breeding screen and three parents; a 0-plate female, a 3-plate female, and a 5-plate male. They must breed the parents as well as F1 offspring, and examine the results in order to update their understanding about how armor is inherited. The challenge culminates with students posting a claim, supported by evidence and reasoning, in the *Journal of Drake Genetics*.

Preparing for Case #16:

1. Review the sample lesson plan for Case #16 and work through the challenge.
2. Determine whether students will work solo or with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for a large-group discussion.
5. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.

Considerations for Case #16:

1. All students receive the same parents at the start of the challenge.
2. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised.
3. Students should save F1 offspring and intercross them as well as backcrossing them to the parents.
4. The data available in the stats tab is critical to solving the challenges. See the User Guide for more information about this feature.
5. It may be useful to review with students what they learned about armor inheritance in Case 12, and to write this information where it can easily be seen by all.
6. Use the magnifying tool to better see the number of armor plates each drake has.

Potential trouble spots:

1. Students who do not plan and keep careful records of their breeding experiments and results are likely to become frustrated trying to solve this challenge.
   a. If you don't use the handouts provided, consider providing another structured means of planning and recording the results from experiments.
   b. While interacting with students as they work, question them as to what drakes they bred, what results they got for a particular breed, and what the data might imply. Then encourage them to summarize in writing what they just told you.

2. If students are having difficulty establishing that this level of armor incorporates two different inheritance mechanisms to result in the four phenotypes, try one or more of the following:
   a. Have them review the number of *possible* phenotypes for the inheritance patterns seen thus far:

i. The single gene, two allele model yields either 2 phenotypes (metallic, wings, forelimbs, hindlimbs, horns, nose spike, and lava/charcoal), or 3 phenotypes (Case #12 armor).
ii. The single gene, three allele model seen with tails provided 3 phenotypes.
iii. The model of two genes, each with two alleles, observed in the second part of Case #11 resulted in four phenotypes (charcoal, steel, lava, copper)
iv. The model of three genes, each with two alleles, observed in Case #14 resulted in eight phenotypes (charcoal, steel, lava, copper, ash, silver, sand, gold)

b. Have students hypothesize and test how this new armor challenge fits with what they learned in Case #12. Guide them to repeatedly:
   i. Predict the outcomes of a breed based on what they learned from Case #12. Punnett squares can be used for these predictions.
   ii. View the stats for the breed and compare these results to their prediction, paying attention to the phenotypic ratio.
   iii. Ask themselves what genotype cross these stats represent (e.g.- homozygous recessive x heterozyote, homozygote x heterozygote w/codominant alleles, etc.)
   iv. Ask themselves if this fits with any of the familiar inheritance patterns.
   v. Repeat as necessary with a new pair of drakes.

c. Suggest to students that they consider that armor is either

   i. The result of a variation of one of these familiar patterns (e.g.- a single gene with more than three alleles, or multiple genes where at least one gene has more than two alleles)
   ii. OR, a combination of inheritance patterns.
   iii. Ask students how they might make testable predictions about these ideas, and have them test these predictions.

Key points:

1. There can be more than two alleles of a gene within a population of organisms, but an individual can still only have two alleles for that gene, one from mom and one from dad.
2. How one pair of alleles interacts may differ from how another pair interacts, and a specific allele may not have the same interaction when paired with different partners.

The Answers:

Claim: Students should somehow indicate that there is one gene for armor, with three possible alleles.

Evidence: Students should provide evidence from breeding experiments. There are many ways they might approach this, and many paths they might take in the order in which breeding experiments are conducted. Described below are some particularly useful breeds.

1. 0-Plate female parent x 5-Plate male parent- [Evidence] Yields 100% 3-plate offspring. [Reasoning] Indicates breeding two different homozygotes to yield heterozygous offspring with a third phenotype. This is what was observed in Case #12, so one could assume the 0-plate female is aa, the 5-plate male is A_1A_1, and the 3-plate offspring are Aa.
2. F_1 intercross of 3-Plate offspring saved from breed #1- [Evidence] Yields 5, 3, and 0-plate offspring in a 1:2:1 phenotypic ratio (as expected from Case #12). [Reasoning] Indicates breeding two heterozygotes w/codominant alleles. This breed could confirm conclusions drawn from Breed #1.
3. 3-Plate female parent x 5-Plate male parent- [Evidence] Yields 100% 5-plate offspring, [Reasoning] ***not expected*** based on Case #12. Breeds 1 & 2 support the 5-plate male parent being A_1A_1, making the 3-plate female parent either heterozygous with one A_1allele and a new allele (call it A_2) that is recessive to A_1 such that the 5-plate offspring would be A_1A_1 or A_1A_2, OR that she's homozygous for a new allele (A_2) that is recessive to A_1 such that the 5-plate offspring would all be A_1A_2.
4. 3-plate female parent x F_1 0-plate male from Breed #2- [Evidence] Yields 100% ***1-plate offspring***. [Reasoning] This is ***not expected*** based on Case #12 and the 1-plate phenotype is new! One can assume the F_1 male is aa, based on Case #12 and his parentage. If the 3-plate female parent were heterozygous (A_1A_2), one would expect offspring genotypes A_1a and A_1A_2 resulting in two phenotypes in a 1:1 ratio. Since there is only one offspring phenotype, one can assume she is homozygous (A_2A_2) and all offspring are aA_2.
5. 0-Plate female parent x F_1 5-plate male from Breed #3- [Evidence] Yields 3 and ***1-plate offspring*** in a 1:1 phenotypic ratio. [Reasoning] This is ***not expected*** based on Case #12 and the 1-plate phenotype is new! Since the 0-plate female parent seemed to act as expected in Breed #1, assume she is aa (as seen in Case #12). This 1:1 phenotypic ratio indicates a homozygous recessive x heterozygous cross where there is one dominant and one recessive allele, but this was not seen in Case #12 and needs further investigation.
6. F_1 intercross of 1-plate offspring saved from Breed #4 or Breed #5- [Evidence] Yields 0, 1, and 3-plate offspring in a 1:2:1 phenotypic ratio. [Reasoning] This indicates a heterozygous x heterozygous cross with codominant alleles. This result would be achieved if the 1-plate offspring had the genotype aA_2. Offspring genotypes would include aa (0-plate), aA_2 (1-plate), and A_2A_2 (3 plate). This fits with the assumption made about the 3-plate female's genotype in Breed #3.
7. Students can test any inferences they draw about the genotype-phenotype connections by performing additional breeds, making Punnett square predictions first and comparing these to the breed results.

<u>Reasoning:</u> Students need to reference the inheritance mechanisms already learned and the stats that support their inferences, as they relate to those inheritance mechanisms. They also should, whether in words or Punnett squares, continue to indicate that offspring receive one copy of each gene from each parent, and that the relationship between these two alleles results in the observed

phenotype. Some*elements* of reasoning are included with the evidence above, but more would be needed to clearly link the evidence to the claim.

Note: If students combine evidence and reasoning in the same part of the scaffold, this is less of a problem than if they exclude evidence and/or reasoning entirely. The teacher will need to determine, based on his/her own setting, how important it is for students to clearly separate these two.

Underlying Genetic Mechanism:

1. In Case #12, students learned that 5 plates (A_1A_1) and 0 plates (aa) were two different homozygous conditions. The 3-plate phenotype was the result of an incompletely dominant relationship between A_1a, the heterozygous condition. These allelic relationships hold true in this case.
2. Case #16 introduces a third allele, which the software labels A_2. The A_2 allele has a different relationship with each of the other two alleles such that:
    a. A_1A_2 = 5 plates; indicating A_1 is dominant to A_2
    b. A_2a = 1 plate; indicating that A_2 and a are co-dominant
    c. A_2A_2 results in 3 plates

3. Here is a summary of the genotypes for each armor plate phenotype:

    a. 0 plates = aa
    b. 1 plate = A_2a
    c. 3 plates = A_1a or A_2A_2
    d. 5 plates = A_1A_1 or A_1A_2

4. So A_1 and A_2 have a dominant/recessive relationship with each other, with A_1 the dominant allele, but both are codominant with a.

The real genes behind these traits:

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

D) Case 17: Frosty's Fate

The **single Challenge** in Case 17 reveals a new color phenotype, Frost, and students must figure out how to incorporate this new phenotype into their existing knowledge of how the color trait works. Now there are nine drake colors: charcoal, steel, ash, silver, lava, copper, sand, gold, and frost. This challenge combines what students learned in past color cases with the new concept of epistasis, where the effects of one gene mask or nullify the effects of others.

Students are presented with a breeding screen and four parents; a gold female, and steel, sand, and silver males. They must breed the parents as well as F1 offspring, and examine the results in order to update their understanding about how color is inherited. The challenge culminates with students posting a claim, supported by evidence and reasoning, in the *Journal of Drake Genetics*. The fourth cartoon panel of Arrow's story unlocks upon completion of this case, as does Case #18, which will then be visible in the Case Log.

Preparing for Case #17:

1. Review the sample lesson plan for Case #17 and work through the challenge.
2. Determine whether students should work solo or with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for a large-group discussion.
5. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.
6. Determine how to incorporate the story element that unlocks upon completion of this case.

Considerations for Case #17:

1. It is probably best to start by helping students recall what they already know about the inheritance mechanisms behind the three known color genes, and writing this down in a highly visible location.
2. Encourage students to develop and track an organized breeding strategy. They can use the provided handout to keep track of their work.
3. As students form ideas about how the frost phenotype fits with their existing understanding of color, encourage them to test each idea as it arises by performing the necessary breed(s) and recording the results.
4. Encourage students to use Punnett squares to make predictions and check their predictions.
5. Be prepared with some probing questions to ask individuals, groups or the class. Some of these might include:
   a. How does this phenotype seem to compare to the others we've already seen?
   b. What patterns emerge in the data when you breed ___ with ___?
   c. What have you learned or think you've learned from the breeds you've already done?
   d. Which breed provides the most useful information and why?
   e. How many genes seem to be involved and what is your evidence?
   f. How many alleles seem to be involved and what is your evidence?
   g. How many phenotypes are possible given the three color genes with which we are already familiar? (8)

h. How can we account for an additional phenotype, Frost? (New allele for one of the 3 known genes? New gene?)

6. If most of the class seems stuck, it might be helpful to bring them together to share their ideas, recording them in a visible place to which they can refer later.
7. This is a very challenging problem to solve. Allow students as much time to work on this as is possible, solo and/or guided, and celebrate how far they have come. The answer can always be provided in the end.

Potential trouble spots:

1. Students who do not keep accurate records of their breeding experiments will probably become frustrated. If the provided handouts are not used, students will need another means of organizing and recording breeds and their results.
2. In classes with low frustration thresholds, it may be useful to work together to develop a breeding strategy before launching into the activity solo or in teams. Here are some ideas toward which to guide students if they get stuck:
   a. Breed the gold female to each male in turn and save several different colored males and females (F_1 generation) from each breed.
   b. Backcross these saved (F_1) males to the gold female parent (because she was known to have produced a Frost drakeling in the past).
   c. Intercross some of the saved F_1 males and females.
   d. Save a male and a female Frost colored drake when they appear.
   e. Backcross a saved male Frost drake to the gold female parent.
   f. Intercross the saved Frost drakes to other F_1 drakes.

3. The work of #2 above could be divided among groups. Each group could breed one female/male parent combination and follow the remaining steps above using drakes from this lineage. They would then reconvene to share and discuss their results, analyze patterns in the data, and determine next steps.
4. Here are a couple of hints that might be shared with students when the teacher deems it prudent to do so:
   a. Whether Frost is a result of a new gene or a new allele for an old gene, the alleles are interacting in a way already familiar to them.
   b. If students ignore the fact that some drakes are frost-colored (but don't leave out breeding frost drakes) ask them if they can apply what they already know about the three known color genes to the outcomes from some of their breeds.
      i. This will be easier if students use Punnett squares to make and check predictions.
      ii. It can be useful to breed a frost drake to each parent, one at a time. Interpreting these results requires referring to earlier breeds between the gold female parent and each male parent, because those established the genotypes of each parent for the three known color genes.

Key points:

1. Sometimes the expression of one gene affects the expression of one or more other genes. This is referred to as *epistasis*.
2. **Note for teachers:** The term epistasis is used differently in different biological fields of study. Geniverse uses a biological model of epistasis and the chosen mechanism is based on that for coat color in mice and other mammals. In the study of diseases, the meaning and identification of epistasis become more complex. Here are some further sources of information about epistasis, the last being appropriate for college-level students.
   a. Talking Glossary of Genetic Terms (http://www.genome.gov/glossary/index.cfm)
   b. Epistasis: Gene Interaction and Phenotype Effects (http://www.nature.com/scitable/topicpage/epistasis-gene-interaction-and-phenotype-effects-460)
   c. Epistasis: What it means, what it doesn't mean, and statistical methods to detect it in humans (http://hmg.oxfordjournals.org/content/11/20/2463.full#T3)

The Answer:

Claim: Frost results from a fourth color gene whose effect masks the effects of the other three color genes.

Evidence: What students submit for evidence will vary greatly. Here are some key breeds to look for. A combination of such evidence will be needed to build a coherent argument to support the claim.

1. The various parent combinations produce the following results.
   a. Gold x Steel --> all colors except Frost
   b. Gold x Sand --> Gold & Sand drakes
   c. Gold x Silver --> Ash, Gold, Sand & Silver drakes

2. Backcrossing an F1 male from breed 1a or 1c above to the gold female parent results in the following:
   a. Frost-colored offspring as well offspring of other colors.
   b. Both male & female Frost colored offspring.
   c. An approximate 3:1 ratio of Frost-colored offspring to Non-Frost-colored offspring.

3. An intercross of two F_1 offspring from breed 1a or 1c, yields similar results to the backcross described above.
4. Backcrossing a Frost offspring from 2b or 3 above to the gold female parent results in the following:
   a. Frost-colored drakes of both sexes, as well drakes of other colors.
   b. An approximate 1:1 ratio of Frost-colored offspring to Non-Frost-colored offspring.

5. A cross between a Frost-colored drake and any F_1 offspring from 1a or 1c yields similar results to the backcross described above in 4.
6. Breeding any two Frost-colored drakes results in only Frost-colored offspring. *[Reasoning: In conjunction with earlier evidence described, this can confirm the recessive nature of frost.]*

Reasoning: Below are *elements* of reasoning associated with each piece of evidence provided above. Individually none would be sufficient to support the claim. More than in any other challenge, students need to piece together observations from an assortment of breeding experiments, and reason about them together.

1. The parent cross results are explainable by applying what is known about the three previously studied color genes. This knowledge carries over to all breeds if one ignores any Frost drakes that appear in a clutch. It can also be applied to crosses between a Frost-colored drake and any other colored drake. This, in conjunction with other evidence can support the argument that Frost is controlled by a separate gene.
2. Backcrossing an F1 male from breed 1a or 1c above to the gold female parent:
    a. A Frost-colored drake resulting from a cross between two non-Frost-colored drakes can serve as evidence for a recessive aspect to Frost, but additional evidence is needed to make this argument.
    b. Having both male and female Frost offspring indicates that Frost is not X-linked, because if it were, all the Frost drakes would be either male or female, but not mixed.
    c. For Mendelian traits, the 3:1 ratio tends to indicate a heterozygote x heterozygote cross. One would have to hypothesize that Frost is caused by such a gene, working independently of the three known color genes, then provide further evidence to support this.

3. The reasoning would be similar to 2 above for students who provide data from an intercross of two F_1 offspring from breed 1a or 1c.
4. Backcrossing a Frost offspring from Evidence 2b or 3 to the gold female parent.
    a. Having both male and female Frost offspring indicates that Frost is not X-linked.
    b. If Frost is ignored, students can use their knowledge of the three known color genes to explain the rest of the results from this breed, which gives support to Frost resulting from a separate gene.
    c. For Mendelian traits, a 1:1 ratio tends to indicate a heterozygote x homozygous recessive cross. In combination with Evidence 2, this strengthens an argument that there is a recessive aspect to Frost and may also lead students to hypothesize that there is a fourth gene at work.

5. The reasoning would be similar to 4 above for students who provide data from a cross between a Frost-colored drake and any F_1offspring from Evidence 1a or 1c yields.
6. In conjunction with earlier evidence described, breeding any two Frost-colored drakes and getting only Frost-colored offspring can confirm the recessive nature of frost.

Note: If students combine evidence and reasoning in the same part of the scaffold, this is less of a problem than if they exclude evidence and/or reasoning entirely. The teacher will need to determine, based on his/her own setting, how important it is for students to clearly separate these two.

Underlying Genetic Mechanism:

Frost is the drake equivalent of albinism. It is an autosomal recessive condition that results from a gene whose effect is epistatic to the effects of the other three color genes. The dominant allele is represented by “C”, the recessive allele by “c”. Frost drakes have the genotype cc at this locus. Drakes of any other color have the genotype of C*.

The C gene is part of the pathway for creating the pigments that produce color in drakes. The other three genes have an effect on this pigment. In cc drakes, since the pigment is not produced, the effect of the other three genes are not observable. However, the genotype for a Frost drake at these other three loci can be determined by breeding the Frost drake to a colored drake, preferably a sand drake who is recessive for all alleles at all three loci.

The real genes behind these traits:

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.

E) Case 18: Bog Breath

The **single Challenge** in this case becomes available in the Case Log only after students have successfully completed the Journeyman Certification Exam.* In this challenge students solve for Arrow’s illness. They are presented with a breeding screen and four parents; healthy copper and steel females, and sick sand and silver males. As in other Journeyman and Master level challenges, students must breed the parents as well as F1 offspring, and examine the results to determine how Arrow’s illness is inherited. Students must draw upon their knowledge of the various inheritance patterns from prior challenges and apply this knowledge to identify how the illness is inherited.

Posting a claim about the inheritance of this disorder in the Journal of Drake Genetics unlocks the final level of the Gene to Protein Genie, where students then identify the chromosome on which the gene is located, and identify which of several genes is the most likely candidate for the cause of this disease. Once the correct gene is identified, the Challenge culminates with students gaining access to the final cartoon panels that resolve the on-going storyline. This is the final portion of the Geniverse program.

Upon completion of Case #18, the Bog Breath Level of the Gene-to-Protein Genie is unlocked and used to determine which gene is causing Arrow's illness. Once this gene is correctly identified, the final cartoon panel unlocks to resolve Arrow's story and that of your avatar.

**Students who have successfully completed through Case #9 (nose spike) have the background they need to complete Case #18. If the teacher does not plan to proceed through all the cases but would still like to have students resolve Arrow's illness, the case can be unlocked from the Home Screen. The user needs to click on the small mirror on the office wall to the right of the column at mid-screen, then enter the code vroom when prompted and click <Process>.*

Preparing for Case #18:

1. Review the sample lesson plan for Case #18 and work through the challenge.
2. Determine when students should work solo and with peers. Have a plan for what students should do if they finish before others.
3. Determine if students will record their work using the in-software electronic notepad, using the relevant handouts, or by another means.
4. Determine when and how you will convene the class for large-group discussions.
5. Decide in advance whether or not the arguments students generate will be graded. Provide the necessary criteria and scoring guide or rubric in advance. Suggestions for what to look for in student arguments are in the answer section at the end of this case.
6. Determine how to incorporate the story element that unlocks upon completion of this case.

Considerations for Case #18:

1. Although this case is intended to serve as the resolution to Arrow's storyline, it can be solved independently of the storyline.
   a. If being used independently of the storyline, approach it as you have the other cases and ignore any cartoon panels and Gene-to-Protein Genie links that unlock.
   b. If being used to resolve Arrow's story, students will need to have done the following prior to starting Case 18:
      i. Successfully completed Cases 1-9 of Geniverse.
      ii. Read the 4 cartoon panels that unlocked before this case (after Cases 5, 10, 15, and 17).
      iii. Explored the Gene-to-Protein Genie at least once for familiarity. A different level of the Genie unlocks after each of Cases 6, 9, 14, and 17.
      iv. The *vroom* instructions, described in the overview of this case above, make accessible any cartoon panels and Gene-to-Protein Genie levels not already unlocked.

2. If being used to resolve Arrow's story, students will need time to do the following after posting their claim for this Case:

a. Follow the link that unlocks for the Bog Breath Level of the Gene-to-Protein Genie and examine the four new genes there (SDH, YO, OTC, and GPI) to determine which is responsible for Arrow's illness.
b. Read the final cartoon panel that unlocks ("The Beginning of the End") to read about Arrow's treatment, and to select their preferred ending to the story.

3. Help students review the inheritance patterns they've already learned through Geniverse, attaching each to specific drake traits.
4. All students receive the same parents at the start of the challenge.
5. This is an argument case. In the full version of Geniverse, students post their claims, supported by evidence and reasoning, in the Journal (J+ icon). The Journal is not available through the Demo version, so an alternative method will need to be devised.
6. Encourage students to develop and track an organized breeding strategy. They can use the provided handout to keep track of their work.
7. As students form ideas about how the disease is inherited, encourage them to test each idea as it arises by performing the necessary breed(s) and recording the results. Encourage students to use Punnett squares to make and test these ideas.
8. Students should save F_1 offspring and intercross them as well as backcrossing them to the parents. They may also need to use F_2offspring in their breeding experiments.
9. The data available in the stats tab is critical to solving the challenges. See the User Guide for more information about this feature.
10. The disease is linked to another gene explored earlier in Geniverse.
    a. An understanding of linkage is not necessary to solve the challenge. The mutant allele is inherited in a manner already experienced by students earlier in Geniverse.
    b. For students who are ready, linkage can be introduced.
    c. The two genes are tightly linked. It is likely that much breeding will have to happen before a crossover is observed.
    d. The stats tab does not provide the necessary data for recognizing the linkage phenomenon. Students would need to observe and count drakes from within the breeding pen.

11. Be prepared with some probing questions to ask individuals, groups or the class. Some of these might include:
    a. What patterns emerge in the data when you breed ___ with ___?
    b. What have you learned or think you've learned from the breeds you've already done?
    c. Which breed provides the most useful information and why?
    d. How many genes seem to be involved and what is your evidence?
    e. How many alleles seem to be involved and what is your evidence?
    f. How does this trait seem to compare to the others we've already seen?

Potential trouble spots:

1. As in all Geniverse Challenges, students who do not keep accurate records of their breeding experiments will probably become frustrated. If the provided handouts are not used, students will need another means of organizing and recording breeds and their results.
2. Stress the importance of developing a breeding plan before starting to breed. If students struggle with this on their own, have them plan their breeding strategy either in small groups or as a whole-class.
3. There are four potential parent crosses to be done. These could be divided among groups, with each group breeding one parent combination and continuing further breeding within that lineage only. They would then need reconvene as a whole class to share and discuss their results, analyze patterns in the data, and determine next steps.

The Answer:

<u>Claim:</u> Bog Breath is a sex-linked trait.

<u>Evidence:</u>Since all combinations of parent crosses yield the same results within a lineage, there are a variety of breeds students might present as evidence. The more breeds they can link to their claim, the stronger the argument. Here are a couple of key breeds important to developing an argument to support this claim:

1. Intercrossing the F_1 offspring from any parent breed results in an F_2 generation where all the female offspring are healthy, while about half of the male offspring have Bog Breath and the other half are healthy.
2. Backcrossing an F_1 female to either male parent produces both sick and healthy males and females.
    a. The ratio of sick:healthy is approximately 1:1.
    b. The ratio of of sick to healthy males is approximately 1:1.
    c. The ratio of of sick to healthy females is approximately 1:1.
3. Crossing a sick female to a healthy F_1 male produces all healthy females and all sick males.

<u>Reasoning:</u> In general, the more evidence linked to a claim, the stronger the argument. The teacher needs to decide what counts as sufficient evidence, based on his/her situation. Here are some principles students should reference in their reasoning.

1. Males have only one X chromosome, received from the mother. If a disease allele is on that chromosome, the male offspring will be sick. If a male receives the healthy allele, he will be healthy.
2. Sick males have the disease allele and pass it to each daughter.
3. There is a 50% chance for each X chromosome to be passed to each offspring.

4. When a sick female and a healthy male produce all sick males and all healthy females, one can infer that the disease is sex-linked and recessive. Each offspring receives a disease allele from its mother. Daughters receive the healthy allele from their fathers. These female offspring are carriers and can pass the disease to their offspring when bred with a sick male.

Key points:

1. Bog Breath is a sex-linked disease with the gene located on the X chromosome. It is therefore inherited in the same way as the nose spike trait.
2. Homozygous recessive female drakes have Bog Breath, heterozygous females are carriers, and since males have only one X chromosome, a single recessive allele results in their having Bog Breath.
3. Heterozygous females (carriers) have a 50% chance of passing on the disease to their male offspring.
4. Each allele for a gene has its own DNA sequence which is code for making a protein that has a specific job in the body. Differences in the code between alleles for a trait result in different proteins that affect the same trait differently. Sometimes, as in the case with Bog Breath, the resulting protein cannot do its job, which can result in disease.

Questions for Deeper Thinking:

1. You may have noticed that drakes with bog breath are almost always light colored (Ash, Sand, Silver, Gold). What might explain why light-colored drakes with bog breath are so common while dark-colored drakes with bog breath are so rare?

Answer: The OTC gene and the Dilute gene are very close together on the X chromosome, so crossover rarely occurs between the two and whichever alleles are at those two locations end up in the same gamete. This is referred to as linkage. In drakes, the faulty OTC allele is linked with the recessive allele of the Dilute gene, which makes drakes light-colored. Dark-colored drakes with bog breath are rare, because a crossover between these tightly linked genes is required so that the faulty OTC gene ends up on the same chromosome as the dominant allele for the Dilute gene, and that is a rare occurrence.

2. Why is bog breath linked to only the recessive allele of the dilute gene and not to the dominant one?

Answer: It is likely that an initial mutation resulting in the faulty otc allele that causes bog breath occurred on a chromosome that also held a recessive dilute allele that makes drakes light-colored. This combination would have passed on to the offspring receiving the gamete with that pairing, and then on to at least 50% of his/her descendants.

Underlying Genetic Mechanism:

Bog Breath is a recessive, X-linked disease with two alleles: OTC (healthy phenotype) and otc (Bog Breath phenotype, recessive).

- Healthy females: $X^{OTC}X^{OTC}$, $X^{OTC}X^{otc}$ (carrier)
- Healthy males: $X^{OTC}Y$
- Sick females: $X^{otc}X^{otc}$
- Sick males: $X^{otc}Y$

The real genes behind these traits:

All drake traits are based on genes from real organisms. Stay tuned for this information as we continue to build these materials.