

The Cotton-Swab Orchard: How Do Bees Turn Blossoms into Almonds?

Investigation question: In a model almond orchard, how do the arrangement of two varieties and the number of bee visits change how many blossoms receive pollen from the other variety and can set a nut?

Physical model

Groups of 4

1 session

Setup 5 · Activity 45 · Cleanup 5 min

MS-LS2-5 · practice

MS-LS2-2 · supports

Scientific purpose

Students build a paper orchard of 20 blossoms in two almond varieties and act as honey bees, carrying chalk 'pollen' on a cotton swab from blossom to blossom by a dice rule. They count which blossoms received pollen from the other variety, compare three planting layouts and a half-the-bees trial, and pool class data. The results become evidence for explaining cross-pollination and for evaluating the ways real growers keep pollination reliable: renting hives, planting pollinizer rows close together, supporting wild bees and planting self-fertile varieties.

Why this helps students with this chapter

Pollination happens too fast and too small to watch across a whole orchard, and it is over in a few weeks. Carrying the pollen with their own hands, students discover that a visit is not enough: the pollen has to come from a different variety, and the way the trees are planted changes how often that happens. Numbers from their own trials turn the growers' choices (rows, hives, hedgerows, self-fertile trees) into a reasoning problem instead of a fact to memorize.

Standards connections

MS-LS2-5 (practice, evaluating competing solutions for maintaining a pollination service): In q9 students judge four ways a grower could keep pollination reliable against a criterion and a constraint, using their model data and an information card. The solutions are evaluated rather than designed and the evidence comes from a simplified model, so this is practice toward the PE that Lab 3 assesses.

MS-LS2-2 (supports, a mutually beneficial interaction between pollinators and plants): The service rests on the bee-blossom mutualism from Lesson 21: bees get nectar and pollen as food, and the plants get pollen carried to other plants. The lab uses that interaction as background rather than asking students to predict interaction patterns across ecosystems.

Roles (rotate each session)

- **Bee:** Moves the swab one blossom per visit by the die rule, delivers pollen to the stigma, then loads pollen from the petals, and grooms the swab every fourth visit.

- **Navigator:** Draws the starting blossom, rolls the die, calls each move aloud, rerolls moves that would leave the orchard, and tallies visits.
- **Inspector:** After each trial checks every stigma label with a hand lens and calls O (other-variety color), S (own color only) or N (no chalk).
- **Recorder:** Fills the group data table, calculates nut set, posts results to the class table, and makes sure roles rotate so everyone is the Bee at least once.

Materials

Item	Quantity	Per	Note
Orchard mat: a printed sheet with 20 blossom outlines (about 4 cm across) in 4 rows of 5, numbered 1-20	3 (one per layout)	group	Mark each blossom B or P lightly in pencil following the layout key on the recording sheet.
Sidewalk chalk, one blue stick and one pink stick (any two strongly contrasting colors)	1 of each color	group	
Cotton swabs	6	group	One per trial plus spares.
Round white sticky labels about 13-19 mm across (office dot labels), used as stigmas	about 90	group	Twenty per trial for four trials, plus spares.
Standard six-sided die	1	group	
Paper slips numbered 1-20 in a cup, for choosing a random starting blossom	1 set	group	
Paper towel (the bee's grooming cloth)	2	group	
Hand lens or magnifier	1	group	Optional; helps judge faint chalk.
Tray, newspaper or scrap paper under the mats to catch chalk dust	1	group	
Recording sheet	1	student	

Estimated cost: 6 to 12 per class (estimate) (an estimate; A box of 500 cotton swabs about \$3, a pack of 1,000 round labels about \$5 to \$8, and a bucket of sidewalk chalk about \$5 that lasts many classes; dice, hand lenses and printing from classroom stock. Estimated 2026 U.S. retail prices; they vary by store.)

Safety

- Chalk dust can irritate eyes and airways. Rub chalk gently, never blow on the mats, and keep dust on the tray; students with asthma can take a role that does not handle chalk.
- Cotton swabs stay out of ears, noses and mouths; use one swab per trial and throw it away afterward.
- Wash hands after the lab, because chalk on fingers ends up in eyes and on food.
- No live bees or real flowers are used. If you add real blossoms as a demonstration, check first for pollen allergies.

Teacher preparation and setup

1. Print three orchard mats per group: 20 blossom outlines in 4 rows of 5, numbered 1-20 in reading order (row 1 is the top row). Label them Layout 1 Blocks, Layout 2 Alternating rows and Layout 3 Mixed in rows, and lightly pencil B or P in each blossom using the layout key on the recording sheet.
2. Run one 20-visit trial yourself before class to check that the chalk transfers visibly from swab to label and to time a trial; aim for about 3 minutes of visits plus 2 minutes of inspection.
3. Cut and number 20 slips per group for choosing a random starting blossom, and put out the die, swabs and labels in a kit per group.
4. Draw the class data table on the board (groups down the side, the four trials across the top) so groups can post results as they finish.
5. Check for students with asthma or dust sensitivity; chalk dust is light, but they can take the Navigator or Recorder role.

Investigation design

Independent variable	Orchard layout (blocks, alternating rows, mixed in rows) in Trials 1-3; number of bee visits (20 or 10) on the alternating-rows layout in Trials 2 and 4.
Dependent variable	Number of blossoms whose stigma shows the other variety's pollen (blossoms that can set a nut), reported as nut set percent; also the counts of own-pollen-only (S) and unvisited (N) blossoms.
Controlled	The same 20 blossoms, 10 of each variety, on every mat; The same visit rule (deliver, then load) and grooming every fourth visit; The same movement rule and a random starting blossom drawn from the slips; The same swab type, chalk colors and amount of chalk on the petals; Fresh stigma labels and a fresh swab for every trial
Trials	Each group runs four trials; the class pools results so each condition has as many trials as there are groups (about eight).
Comparison	Layouts are compared at 20 visits (Trials 1-3); visit number is compared on the alternating-rows layout (Trial 2 versus Trial 4).

Student procedure

1. Read the recording-sheet background and layout key, then answer q1: predict which layout will set the most nuts in 20 visits, using the bee's movement rule in your reasoning.
2. Prepare the mats. Rub chalk on the petals of each blossom in the color marked (B blue, P pink) until they are well dusted; leave the center white. Stick a fresh white label in the center of every blossom: it is that blossom's stigma.
3. Learn the visit rule. At each visit the Bee (a) presses the swab tip once on the stigma label to deliver whatever pollen it carries, then (b) rolls the swab tip once around that blossom's petals to load its pollen. After every fourth visit, the Bee wipes the swab twice across the paper towel, standing for the way bees groom much of their pollen into their pollen baskets.

4. Learn the movement rule. Draw a slip to choose the starting blossom. Before each later visit the Navigator rolls: 1 or 2 = one blossom right along the row, 3 or 4 = one blossom left along the row, 5 = up one row, 6 = down one row. If the move would leave the orchard, roll again. Revisiting a blossom counts as a visit. (Observers often report that honey bees work along a tree row more than across rows; this rule builds in that tendency.)
5. Trial 1: run 20 visits on Layout 1 (Blocks) with a new swab. The Inspector then checks every stigma and records O (shows any of the other variety's color), S (shows only its own variety's color) or N (no chalk). Only an O blossom can set a nut.
6. Rotate roles. Replace all 20 stigma labels, re-dust any faint petals, and run Trial 2 on Layout 2 (Alternating rows) and Trial 3 on Layout 3 (Mixed in rows), 20 visits each with a new swab each time.
7. Trial 4, half the bees: run Layout 2 again with only 10 visits. For every trial calculate nut set (%) = number of O blossoms / 20 x 100.
8. Post your four nut-set results on the class table, copy the class data, compute the class mean for each trial, plot the means on the graph, and answer q2-q5 as a group.
9. Clean up: peel off and discard labels and swabs, fold the chalk dust into the newspaper and throw it away, wipe trays, and wash hands. Answer the analysis questions individually in class or for homework.

Expected observations

- Predicted pattern, not yet confirmed in a classroom (from running the same rules many times on a computer with assumed chalk carryover): Blocks lowest, about 0-6 of 20 blossoms with other-variety pollen in 20 visits (class mean near 15 percent); Alternating rows about 4-9 of 20 (near 35 percent); Mixed in rows about 7-12 of 20 (near 45 percent).
- Halving the visits on alternating rows (Trial 4) roughly halves nut set, to about 1-5 of 20 blossoms (near 17 percent).
- Blocks produce the most S blossoms (own pollen only), often 4 to 9: the bee visits plenty of blossoms but carries the wrong pollen. Mixed rows produce almost none.
- No layout comes close to 100 percent in 20 visits, because the bee revisits some blossoms and never reaches others; many blossoms stay N.
- Single-group results vary widely from trial to trial; the class means separate the layouts much more clearly than any one group's numbers.

Likely difficulties

- Loading before delivering. The order matters: press the stigma first (deliver), then roll the petals (load). Reversing it gives every stigma its own color first and blurs the results.
- Chalk that is too faint to see on the swab, or petals so heavily chalked that dust falls onto the labels. Re-dust lightly between trials and tap off loose dust.
- Forgetting to groom every fourth visit, which lets pollen carry over for many visits and makes the layouts look more alike.
- Steering the bee instead of following the die, often toward the other color. The Navigator calls every roll aloud.

- Counting a fingerprint smudge as pollen. Inspectors should look for chalk in the center of the label where the swab pressed.

Structured debrief

- Post the class means and ask what pattern holds across groups even though single trials varied. In the expected pattern, mixed rows set the most nuts, blocks the fewest, and halving the visits cut nut set roughly in half. Ask groups to explain the order with the movement rule: crossing to the other variety happens only at the middle boundary in blocks, on up-or-down moves in alternating rows, and on every move in mixed rows.
- Spend time on the S blossoms. Blocks produce many blossoms that were visited and carry pollen but cannot set a nut, because the pollen is their own variety's. That is self-incompatibility, and it is why growers plant pollinizer varieties and why self-fertile varieties need fewer bees.
- Connect to the bee trucks: renting hives is a technological substitute for a pollination service the landscape no longer provides in full. Run a quick gallery of q9 answers and look for groups that combined a fast fix (more hives) with a slow one (hedgerows or self-fertile trees).
- Close on q7 and q10: the model's best layout is not the real growers' choice, because harvest timing, cost and real bee behavior are criteria too, and a model with one swab and a die leaves out weather, thousands of bees and the biology of the tree.

Recording sheet: what students fill in

Lab 1 recording sheet: The Cotton-Swab Orchard

Most almond varieties cannot be fertilized by pollen from their own variety. A blossom can set a nut only if a pollinator brings pollen from a **different, compatible variety**. In this model, **blue (B)** blossoms are the main variety (call it Nonpareil, the most widely planted variety) and **pink (P)** blossoms are a pollinizer variety planted to supply compatible pollen. The chalk on the petals is pollen, the white label in the center is the stigma, and your cotton swab is one honey bee.

Layout key: B = blue, P = pink, rows listed from the top

Row	Layout 1: Blocks	Layout 2: Alternating rows	Layout 3: Mixed in rows
Row 1	B B B B B	B B B B B	B P B P B
Row 2	B B B B B	P P P P P	P B P B P
Row 3	P P P P P	B B B B B	B P B P B
Row 4	P P P P P	P P P P P	P B P B P

- Before you start: which layout do you predict will set the most nuts in 20 visits, and which the fewest? Use the movement rule (bees mostly move along rows) in your reasoning.

Answer: Any prediction with reasoning. The prediction the model supports: mixed in rows most, blocks fewest, alternating rows in between, because bees mostly move along rows; in mixed rows every move reaches the other variety, in alternating rows only up-or-down moves do, and in blocks only moves across the middle boundary do.

Why: A prediction is not graded for being right; credit goes to reasoning that uses the movement rule and the need for other-variety pollen.

- Names a highest and a lowest layout
- Reasoning refers to how the bee moves or how often it crosses between varieties

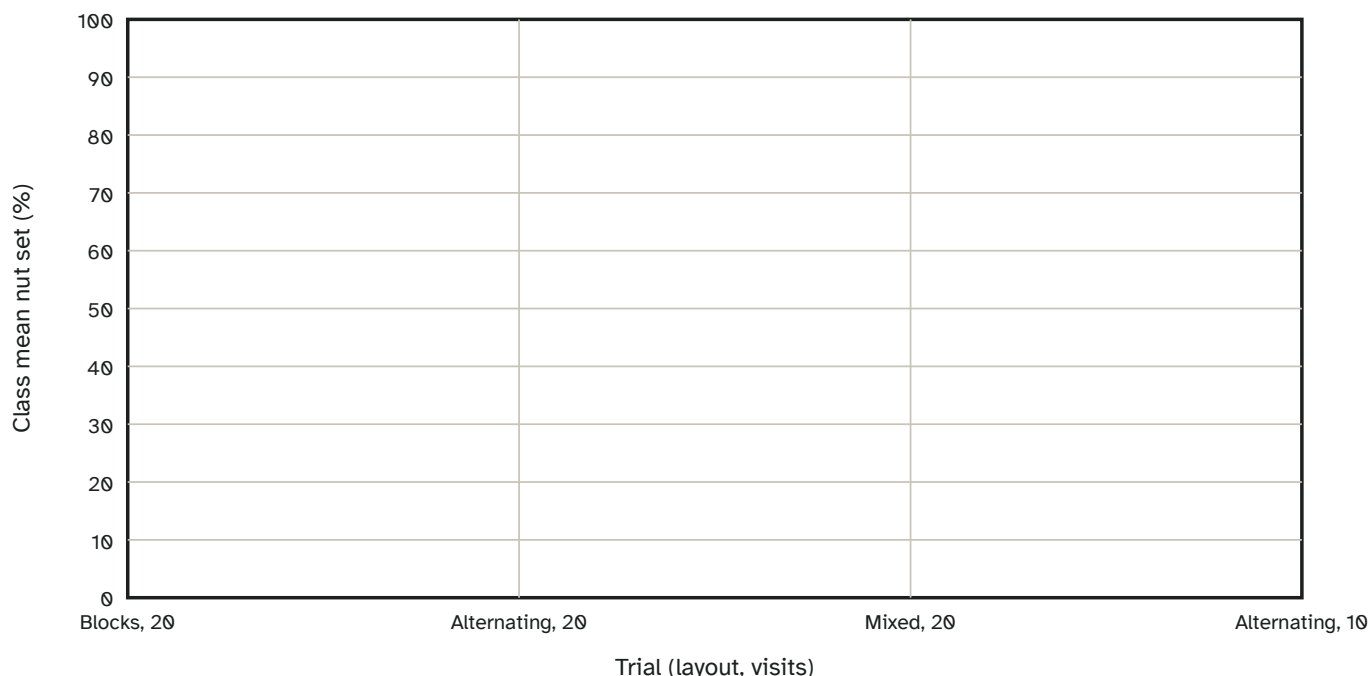
Group data (O = other-variety pollen, S = own pollen only, N = no pollen)

Trial	Layout	Visits	O blossoms	S blossoms	N blossoms	Nut set (%) = $O / 20 \times 100$
1	Blocks	20				
2	Alternating rows	20				
3	Mixed in rows	20				
4	Alternating rows	10				

Class data: nut set (%) for each trial

Group	Trial 1: Blocks, 20 visits	Trial 2: Alternating, 20 visits	Trial 3: Mixed, 20 visits	Trial 4: Alternating, 10 visits
Group 1				
Group 2				
Group 3				
Group 4				
Group 5				
Group 6				
Group 7				
Group 8				
Class mean				

Class mean nut set for each trial



2. Which trial had the highest class mean nut set, and which had the lowest? Give both numbers.

Answer: Class-specific. Expected: highest is Trial 3 (mixed in rows, near 45 percent); lowest is Trial 1 (blocks, near 15 percent) or Trial 4 (alternating with 10 visits, near 17 percent).

Why: Students must read both values from their class table; check that they report means, not one group's numbers.

- Highest and lowest trials named
- Both class-mean values given

3. How many S blossoms did your group find in Trial 1? Explain why a blossom that was visited, and has pollen on its stigma, still cannot set a nut.

Answer: Group-specific count, often 4 to 9 S blossoms in Trial 1. The blossom received pollen only from its own variety. Almond varieties are self-incompatible: pollen from the same variety cannot fertilize the ovule, so no seed (nut) forms however much of it lands on the stigma.

Why: In blocks the bee spends most visits inside one variety's block, so it mostly delivers own-variety pollen.

- Gives the group's S count
- States that own-variety pollen cannot fertilize an almond blossom
- Connects to the need for a different, compatible variety

4. Compare the class means for Trial 2 and Trial 4. By what percent did nut set change when the bees made half as many visits? Show your calculation.

Answer: Percent change = (Trial 4 mean - Trial 2 mean) / Trial 2 mean x 100. Example with expected means: $(17 - 35) / 35 \times 100 = -18 / 35 \times 100 = \text{about } -51 \text{ percent}$, so nut set fell by about half.

Why: Half as many visits reach roughly half as many blossoms, so nut set falls roughly in proportion at this low number of visits. Accept any correct calculation from the class's own means.

Also acceptable: Students who report the change in percentage points ($35 - 17 = 18$ points lower) earn partial credit if they say 'points'; full credit requires the relative change.

- Uses the class means for Trials 2 and 4
- Correct percent-change formula with work shown
- States the direction (a decrease)

5. How much did different groups' results vary for the same trial? Why does pooling the class data give a more trustworthy comparison than one group's single trial?

Answer: Groups' results for the same trial usually differ by several blossoms because the starting blossom and the die rolls are random. Pooling about eight trials averages out that chance, so a difference between class means is much more likely to come from the layout than from luck.

Why: This is the idea of replication; a single trial can easily mislead.

- Describes the spread between groups with an example
- Names chance (random start and rolls) as the cause
- Explains that averaging many trials makes the comparison more reliable

Information card: ways to keep an orchard pollinated — Rent more hives: works within a single season, but price and supply change from year to year, and colonies can be weakened by mites, viruses, poor nutrition and long trips. Honey bees fly little in cold, rainy or windy weather. **Hedgerows and cover crops:** flowering shrubs and ground plants, plus places to nest, let native bees such as the blue orchard bee live near the orchard. A study of 23 California orchards found wild bees on almond blossoms only where natural habitat or a strip of semi-natural vegetation was next to the trees, and a strip helped mostly at the orchard edge. A hedgerow takes a few years to grow and uses some land. **Self-fertile varieties:** can set nuts with their own pollen, so growers usually stock about half as many hives, though bees still raise yields; new trees take several years to start bearing. **Pollinizer rows close together:** planting a compatible variety in every other row shortens the trips bees must make; the varieties must bloom at the same time.

Analysis questions: answer key

6. Use the movement rule to explain the order of the three layouts in your class data. Why does the layout change how often the bee arrives at a blossom carrying the other variety's pollen?

Answer: Most rolls (four of six) move the bee along its row. In blocks, a whole row and its neighbors are one variety, so the bee only reaches the other variety by an up-or-down move across the middle boundary, which is rare; most deliveries carry its own variety's pollen. In alternating rows, every up-or-down move lands in the other variety, so about one move in three crosses, and after crossing the swab still carries the old variety's pollen for a few visits. In mixed rows every move, along or across, lands on the other variety, so nearly every delivery carries compatible pollen. More crossings means more blossoms receive the other variety's pollen.

Why: The ranking follows from how often a move crosses between varieties under the die rule.

- Uses the movement rule (mostly along rows)
- Explains crossing frequency for all three layouts
- Links crossings to O blossoms (other-variety pollen)

7. Real growers mostly plant alternating solid rows, not varieties mixed within each row, even though mixing may set the most nuts in this model. Mixed rows are harder to harvest because varieties ripen at different times, and field trials have not shown consistently higher yields. What does this tell you about choosing a design using only one criterion?

Answer: A design that is best on one criterion (nut set in a model) can fail others that matter: harvest cost and timing, labor, and whether real yields actually improve. Engineers and growers judge a design against all the criteria and constraints, and they test it in the real setting before trusting a model's best answer.

Why: Evaluating competing solutions requires weighing several criteria, including economic and practical ones.

- Says one criterion is not enough
- Names at least one other criterion or constraint (harvest, cost, real yield)
- Mentions testing in real conditions or trade-offs

8. A grower has 150 acres of traditional almonds and stocks 2 honey bee colonies per acre at \$200 per colony (close to recent averages; real prices vary). (a) How many colonies does the grower rent? (b) What is the yearly rent? (c) If a hive shortage raises the price by 25 percent, what is the new yearly rent?

Answer: (a) $150 \text{ acres} \times 2 \text{ colonies per acre} = 300 \text{ colonies}$. (b) $300 \times \$200 = \$60,000$ per year. (c) A 25 percent rise makes the price $\$200 \times 1.25 = \$250$ per colony, so $300 \times \$250 = \$75,000$ per year (equivalently $\$60,000 \times 1.25$).

Why: Multiply acres by stocking rate, then colonies by price; a 25 percent increase multiplies by 1.25.

- 300 colonies
- \$60,000
- \$75,000 with work shown

9. Use the information card and your data to evaluate the four ways to keep pollination reliable. Which two would you combine for a 150-acre orchard, and why? Name one criterion and one constraint your choice must meet.

Answer: Open-ended. A strong answer: combine closer pollinizer rows or a modest number of rented hives (reliable this season) with hedgerows and cover crops (cheaper over time, support wild bees and other wildlife, reduce dependence on one species), and consider self-fertile trees when old orchards are replanted. Example criterion: enough cross-pollination for a full crop in most years. Example constraint: the yearly budget for hive rent, the land the hedgerow takes, or the years before new trees bear.

Why: MS-LS2-5 asks students to evaluate competing solutions with scientific, economic and social constraints. Any well-argued combination earns credit if it uses the card and the lab data.

Also acceptable: Choosing self-fertile varieties plus hedgerows, or rented hives plus close pollinizer rows, is acceptable if the trade-offs are named (years to bearing, harvest practicality, dependence on hive supply).

- Compares at least three of the four solutions
- Chooses two and explains why they work well together
- Uses at least one fact from the card and one result from the lab
- Names one criterion and one constraint

10. Name two ways a real orchard differs from the cotton-swab model. Explain how one of those differences could change your conclusion about which layout works best.

Answer: Examples: a real orchard has thousands of bees working at once for weeks; trees carry thousands of blossoms; real bees choose flowers by reward and avoid flying in cold or rain; pollen grooming and viability differ from chalk; bloom times of varieties must overlap; frost or drought can drop pollinated blossoms. One effect: with thousands of bees visiting each blossom many times, nearly every blossom in alternating rows might receive compatible pollen, so the difference between alternating and mixed rows could shrink or vanish, which matches field trials that found no consistent yield advantage for mixed rows.

Why: Students should connect a specific model limitation to a specific change in the conclusion.

- Two real differences named
- One difference linked to a possible change in the layout conclusion

11. Before the Central Valley was covered with orchards, what pollinated its wildflowers? Explain why a valley planted almost entirely in one crop supports few wild pollinators, and whether pollination is still a free ecosystem service there.

Answer: Native insects, mainly native bees, along with flies, butterflies, moths and beetles, pollinated the valley's wildflowers. A landscape planted almost entirely in one crop offers flowers for only a few weeks, few places to nest, and pesticide exposure, so few wild pollinators can live there year-round. Pollination is therefore no longer fully free there: growers pay to truck in honey bees. Where natural habitat or hedgerows remain next to orchards, wild bees still provide part of the service for free.

Why: Connects the phenomenon to habitat: a service exists only while the ecosystem that provides it is healthy.

- Names native bees or other insects as the original pollinators
- Explains the year-round food and nesting needs a single crop cannot meet
- Concludes that much of the service is now replaced at a cost, with wild bees still helping near habitat

Individual evidence of learning

Each student submits the group and class data tables, the class graph, and individual answers to q6-q11. q3 and q6 show understanding of cross-pollination and why the layouts differ; q8 is the calculation; q9 is the evaluation of competing solutions with a named criterion and constraint; q10 and q11 show model critique and why pollination depends on habitat.

Assessment criteria

Criterion	Proficient looks like
Data	Group table complete with O, S and N counts that add to 20, nut set calculated correctly, class means computed and graphed.
Explanation of cross-pollination	Explains that own-variety pollen cannot fertilize an almond blossom (q3) and links layout to how often the bee crosses between varieties (q6).
Calculation	q4 percent change and q8 colony count, rent and price increase are correct with work shown.
Evaluation of solutions	q9 compares at least three solutions using the card and the data, combines two with a reason, and names a criterion and a constraint.
Model critique	q10 names two real differences and explains how one could change the conclusion.

Accessibility adaptations

- Print large-format mats with B and P printed inside every blossom, and add a strip of masking tape on pink blossoms so they can be found by touch.
- For limited fine-motor control, use foam makeup swabs, or let a partner move the swab while the student directs and calls the rolls as Navigator.
- Give a nut-set conversion strip (1 blossom = 5 percent, 2 = 10 percent, and so on) and a percent-change frame: $(\text{new} - \text{old}) / \text{old} \times 100$.
- Offer sentence frames for q6 and q9: 'In the ___ layout, the bee crosses to the other variety when ___, so ___' and 'I would combine ___ and ___ because ___; this meets the criterion ___ within the constraint ___.'

Low-cost alternative

With no chalk or labels, run the same dice rule with a sticky note as the bee: the Bee writes the variety of the last blossom visited on the note, and the Inspector marks O on a blossom whenever the note arriving there names the other variety. The data and reasoning stay the same, but students lose the hands-on pollen transfer and the carryover of pollen across several visits. A floor version with 20 students holding blue and pink cards in a 4-by-5 grid works the same way.

Model limitations

This activity has not been physically tested by the authors, and the expected pattern comes from a computer run of the same rules with an assumed amount of chalk carryover, so classroom numbers may differ. Chalk is

not pollen: real pollen sticks to branched hairs, is groomed into pollen baskets and loses viability over hours. One swab stands for one bee, while a real orchard has thousands of bees working for weeks and each tree carries thousands of blossoms. The die rule simplifies bee movement; real bees choose flowers by their reward and stop flying in cold, wet or windy weather. Real nut set also depends on pollen compatibility, bloom overlap, frost, water and nutrients, and many pollinated blossoms still drop. Use the model to compare layouts and visit numbers, not to predict a real orchard's yield.

Teacher notes

Check that $O + S + N = 20$ in every row of the group table before accepting it. The predicted numbers in the expected observations come from a computer run of the rules and are not classroom-tested; if your class's means do not separate the layouts, look first at whether groups delivered before loading and groomed every fourth visit. For q4, use the class's own means. q9 has no single right answer; grade the reasoning with the criteria. If time runs short, assign q6-q11 for homework and use slide 14 the next day to review the S blossoms.