

Pull One Thread: Testing a Prairie Web for Its Keystone

Investigation question: When one part of a shortgrass prairie is removed or weakened, how many other populations change, and does a change to a living part or to a nonliving part send the bigger ripple? Does real survey data agree with what the model predicts?

Collaborative systems modeling

Groups of 4

1 session

Setup 5 · Activity 45 · Cleanup 5 min

MS-LS2-4 · assesses

MS-LS2-1 · supports

Scientific purpose

Students build a fifteen-card interaction web of a shortgrass prairie in which strings stand for food, shelter, water and plant clipping, not just feeding. They run four trials with the same written rules: remove prairie dogs, remove bison, remove grasshoppers, and weaken the soil water with a drought. Working wave by wave, they record how many populations are lost, go down or go up. Comparing the counts shows which change reaches furthest, which species acts as a keystone, and whether a physical change can shift as many populations as a biological one. Groups then test one of the model's predictions against real survey counts of burrowing owls on active and abandoned prairie dog colonies.

Why this helps students with this chapter

The textbook tells students that prairie dogs matter to many species; this lab lets them measure how much, in a model where every link is visible and every effect must follow a stated rule. Counting the ripple from each removal turns 'keystone species' from a label into a result: the bison, the biggest animal on the board, changes one card, while the prairie dog changes twelve. Running a drought through the same web shows that a change to a nonliving part can reach every population. Checking the model against real colony surveys then makes the difference between a model's prediction and empirical evidence concrete, which is exactly the kind of evidence the performance expectation asks for.

Standards connections

MS-LS2-4 (assesses, the closing argument (q9), which uses real survey counts of burrowing owls on active and inactive prairie dog colonies; the string-web trials themselves are practice): Students first practice tracing how a change to a biological component (a species removed) or a physical component (less soil water) shifts populations in a model. They then construct a short argument from published survey data that the loss of prairie dogs affected burrowing owl populations, which is an argument supported by empirical evidence as the PE requires.

MS-LS2-1 (supports, resource availability as the rule behind every change in the model): Every rule in the model is a resource rule: a population goes down or is lost when its food, water or shelter shrinks or disappears. Students apply the resource-population relationship from Lesson 20 rather than producing new evidence for it.

Roles (rotate each session)

- **Card keeper:** Lays out the cards, lifts the removed or lost card at the start of each wave, and resets the board between trials.
- **Rule reader:** Reads each tugged card's needs aloud, applies the rules card, and says which token it gets and why.
- **Token placer:** Places the red, yellow and green tokens and flips LOST cards face down, but only after the group agrees.
- **Recorder:** Fills in the trial table, counts the tokens, and checks the totals against the board before the reset.

Materials

Item	Quantity	Per	Note
Prairie web card set (15 cards from the recording sheet) printed on cardstock and cut apart	1 set	group	Laminate for reuse.
Yarn pre-cut into 50 cm lengths: green (food), brown (shelter), blue (water) and orange (clipping)	32 strings: 22 green, 6 brown, 3 blue, 1 orange (about 16 m in all)	group	Bundle each group's strings by color.
Masking tape	1 roll	group	
Paper tokens about 2 cm square cut from construction paper: red (LOST), yellow (DOWN), green (UP)	15 of each color	group	Print L, D and U on them so they work for color-blind students.
Rules card (the 'Rules for every wave' callout), printed large	1	group	
Two desks pushed together, or a floor area about 1 m by 1.2 m	1	group	
Colored pencils	1 set	group	
Recording sheet	1	student	

Estimated cost: 8 to 14 per class (an estimate; Estimate. Four skeins of acrylic yarn in different colors (about 3 dollars each), about 16 sheets of cardstock for eight card sets, and a few sheets of construction paper for tokens; masking tape and colored pencils are classroom stock. Cards and tokens are reusable.)

Safety

- Yarn is a tangling and tripping hazard. Keep the strings on the desk or floor area, never around a neck, wrist or finger, and coil them before anyone stands up.
- If you build the web on the floor, keep it out of walkways and away from doors; step around the web, not over it.

- Scissors, if used for tape or tokens: cut away from fingers. No other hazards beyond ordinary classroom materials.

Teacher preparation and setup

1. Print one 15-card set per group on cardstock and cut the cards apart. Print the rules callout large enough to read across a desk.
2. Pre-cut the yarn into 50 cm lengths and bundle each group's 32 strings by color: 22 green, 6 brown, 3 blue and 1 orange.
3. Cut the tokens, 15 of each color per group, and store them in an envelope with the cards.
4. Run the prairie dog trial once yourself with the rules so you can coach the wave-by-wave logic. The teacher notes in the answer key list the result of every possible single removal, which you need if groups run trial 5.
5. Post the string list where every group can see it, and decide whether groups may run a fifth trial of their own choice if time allows.

Investigation design

Independent variable	Which part of the web is changed and how: one population removed (prairie dogs, bison, grasshoppers, or the group's choice) or one nonliving part weakened (soil water, in the drought trial).
Dependent variable	How many other cards change, and how each changes (LOST, DOWN, UP or MIXED), counted after the last wave.
Controlled	The same 15 cards and 32 strings for every trial and every group; The same written rules, applied wave by wave; A full reset of tokens and cards between trials; Each card's change decided only from the needs printed on it
Trials	Four required trials per group, plus an optional fifth. Because the rules are fixed, groups that apply them correctly get the same counts, so the class compares totals to catch rule errors.
Comparison	The bison trial (a large animal with a single link) is the comparison for the prairie dog trial, and the drought trial compares a physical change with the biological removals.

Student procedure

1. Lay out the 15 cards about 30 to 40 cm apart: the rain and soil water card along the bottom edge, the three plant cards above it, the plant eaters and the burrows card in the middle, and the predators along the top.
2. Tape one string for every pair in the string list: green for food, brown for shelter, blue for water, orange for clipping. Tape each end to the back of a card so the cards can still slide. Count the strings: there should be 32.
3. Read the rules card together. Each person predicts which card's removal will change the most other cards (q1); write the group's predicted number of changed cards for every trial in the trial table.

4. Trial 1: remove the prairie dogs. The Card keeper slowly lifts the prairie dog card about 20 cm. Every card that slides or tugs is directly linked; those cards make up wave 1. The Rule reader applies the rules to each wave-1 card, and the Token placer puts down tokens and flips any LOST card face down.
5. Next wave: lift each card that was just LOST and apply the rules to the cards it tugs. Also follow DOWN tokens to the cards that need the DOWN card (its eaters, or the users of a shelter or of water). UP tokens stop where they are. Keep going, wave by wave, until a wave adds no new tokens.
6. Record the trial: the number of wave-1 cards, the names of LOST cards, the numbers of DOWN, UP and MIXED cards, and the total number of cards that changed. Then remove every token, flip the cards face up and put the removed card back.
7. Trial 2: remove the bison. Trial 3: remove the grasshoppers. Repeat steps 4 to 6 for each.
8. Trial 4: drought. Do not remove the water card. Put a yellow DOWN token on it, follow its blue strings, and apply the rules wave by wave as before.
9. If time allows, run trial 5 on a card your group chooses, predicting first.
10. Graph the total number of cards changed and the number LOST for each trial. Then read the field evidence, answer q3, and compare it with your model's prediction for burrowing owls.
11. Answer the analysis questions; finish at home if needed. Untape the strings, bundle them by color, and return cards and tokens to the envelope.

Expected observations

- Trial 1 (prairie dogs): 8 cards change in wave 1 and 12 of the other 14 cards by the end. Burrows, black-footed ferrets and burrowing owls are LOST; cottontails, rattlesnakes, coyotes and hawks go DOWN; grasses, wildflowers, shrubs, grasshoppers and deer mice go UP. Only bison and the water card do not change.
- Trial 2 (bison): only the grasses change (UP). Trial 3 (grasshoppers): 7 cards change and none is LOST; grasses and wildflowers go UP, while deer mice, burrowing owls, rattlesnakes, coyotes and hawks go DOWN.
- Trial 4 (drought): all 14 other cards go DOWN over three waves, but nothing is LOST.
- Groups that misapply a rule usually let UP tokens travel, or forget that the burrows card needs prairie dogs and so miss the second wave of trial 1; comparing totals across groups catches both.

Likely difficulties

- Groups let UP tokens travel (for example, more grass making the bison go UP). The rule says UP stops; this is a simplification students should name in q8, not something to fix during the trial.
- Students forget that the burrows card is a nonliving part that depends on a living one. Ask: who digs and repairs the burrows?
- The board gets confusing after several trials. Insist on a full reset (tokens off, cards face up) before each trial, and have the Recorder check totals before the reset.
- Taping 32 strings takes longer than expected. Pre-bundled strings and the posted string list keep it to about 10 minutes; if time runs short, skip trial 5.

Structured debrief

1. Post every group's totals for trials 1 to 4. Where groups disagree, find the rule that was applied differently: the model is deterministic, so differences are rule errors, not data.
2. Ask which removal changed the most, and whether it was the biggest animal. Use the bison-versus-prairie-dog contrast to define a keystone species by the size of the ripple, not the size of the animal.
3. Contrast the drought with the removals: a physical change at the base of the web reached every population, which is why the performance expectation names both physical and biological components.
4. Put the owl table up. The model said LOST; the field said 69 percent of active colonies versus 11 percent of inactive ones. Discuss what the gap means: models make predictions, field data test them, and the mismatch tells us what the model left out.
5. Connect to slide 22: the owl survey has with-and-without comparisons and repetition across hundreds of colonies, but no before-and-after counts on the same colonies. What study would add that?

Recording sheet: what students fill in

Lab 2 recording sheet: Pull one thread

This is a model of a patch of shortgrass prairie on the Great Plains. Each card is one population or one nonliving part, and each string is a link: who eats whom, who shelters where, which plants need the soil water, and which plants the prairie dogs clip. A ★ marks a **MUST HAVE**: if it is lost, the population is lost from this patch.

Prairie web cards (cut apart)

1 Rain and soil water

Nonliving. Rain that soaks into the soil. Needed by: grasses, wildflowers and shrubs. It comes from the weather, outside the model.

2 Burrows

Nonliving structure: tunnels and mounds. Needs: ★ prairie dogs, which dig and repair them; without prairie dogs, burrows cave in and fill with soil over a few years. Shelter for: prairie dogs, black-footed ferrets, burrowing owls, prairie rattlesnakes and cottontails.

3 Grasses (blue grama, buffalograss)

Producer. Needs: ★ rain and soil water. Eaten by: prairie dogs, bison, grasshoppers, cottontails and deer mice (seeds).

4 Wildflowers

Producer: broad-leaved flowering plants. Needs: ★ rain and soil water. Eaten by: prairie dogs, grasshoppers, cottontails and deer mice (seeds).

5 Shrubs (saltbush, rabbitbrush)

Producer. Needs: ★ rain and soil water. Clipped by: prairie dogs, which bite off shrub seedlings and branches near their burrows. Shelter for: cottontails.

6 Black-tailed prairie dogs

Herbivore: a ground squirrel that lives in large colonies. Food: grasses or wildflowers. Needs: ★ burrows. Eaten by: black-footed ferrets, prairie rattlesnakes, coyotes and ferruginous hawks. Also digs and repairs the burrows and clips shrubs.

7 Bison

Herbivore, the largest animal in the model. Food: grasses (its only food here). Eaten by: nothing in this model.

8 Grasshoppers

Herbivore (insect). Food: grasses or wildflowers. Eaten by: burrowing owls and deer mice.

9 Cottontails

Herbivore (a rabbit). Food: grasses or wildflowers. Shelter: burrows or shrubs. Eaten by: prairie rattlesnakes, coyotes and ferruginous hawks.

10 Deer mice

Omnivore. Food: grass seeds, wildflower seeds or grasshoppers. Eaten by: burrowing owls, prairie rattlesnakes, coyotes and ferruginous hawks.

11 Black-footed ferrets

Predator. Food: ★ prairie dogs (almost its only food). Needs: ★ burrows (it lives in prairie dog burrows). Eaten by: nothing in this model.

12 Burrowing owls

Predator. Food: grasshoppers or deer mice. Needs: ★ burrows (on the Great Plains it nests in old prairie dog burrows and seldom digs its own).

13 Prairie rattlesnakes

Predator. Food: prairie dogs, cottontails or deer mice. Shelter: burrows, or rock crevices (not in the model).

14 Coyotes

Predator. Food: prairie dogs, cottontails or deer mice.

15 Ferruginous hawks

Predator: a large hawk of open plains. Food: prairie dogs, cottontails or deer mice.

String list (32 strings)

Color	Link	Tape one string between
Blue	Water	Rain and soil water and each of: grasses, wildflowers, shrubs (3 strings)
Brown	Shelter	Burrows and each of: prairie dogs, black-footed ferrets, burrowing owls, prairie rattlesnakes, cottontails; also shrubs and cottontails (6 strings)
Orange	Clipping	Prairie dogs and shrubs (1 string)
Green	Food	Grasses and each of: prairie dogs, bison, grasshoppers, cottontails, deer mice (5 strings)
Green	Food	Wildflowers and each of: prairie dogs, grasshoppers, cottontails, deer mice (4 strings)
Green	Food	Grasshoppers and each of: burrowing owls, deer mice (2 strings)
Green	Food	Prairie dogs and each of: black-footed ferrets, prairie rattlesnakes, coyotes, ferruginous hawks (4 strings)
Green	Food	Cottontails and each of: prairie rattlesnakes, coyotes, ferruginous hawks (3 strings)
Green	Food	Deer mice and each of: burrowing owls, prairie rattlesnakes, coyotes, ferruginous hawks (4 strings)

Rules for every wave — **LOST** (red token, flip the card face down): you lose every option for one of your needs (all of your foods, or all of your shelters), or anything marked ★. **DOWN** (yellow): you lose one of several foods or shelters, or something you need is DOWN. **UP** (green): something that eats you or clips you is LOST. **MIXED**: you collect both a yellow and a green token. LOST beats everything. **Travel**: a LOST card is lifted in the next wave and tugs all its strings; a DOWN card passes DOWN only to the cards that need it; UP tokens stop where they are. Stop when a wave adds no new tokens.

Trial table

Trial	Change made	Predicted number of cards that change	Wave-1 cards (number)	LOST cards (names)	DOWN / UP / MIXED (numbers)	Total cards changed (not counting the one you changed)
1	Remove prairie dogs					
2	Remove bison					
3	Remove grasshoppers					
4	Drought: soil water DOWN					
5	Your choice: remove _____					

- Before trial 1: predict which single card's removal will change the most other cards, and explain your reasoning.

Answer: Answers vary. Most students predict prairie dogs, because their card has the most strings (8) and is a ★ need for two other cards (burrows and ferrets). Some predict grasses or the water card because everything ultimately eats plants.

Why: Credit any prediction backed by a reason about links. The water and grasses predictions are good reasoning and are partly confirmed by the drought trial.

- Names a card
- Gives a reason based on links or dependence

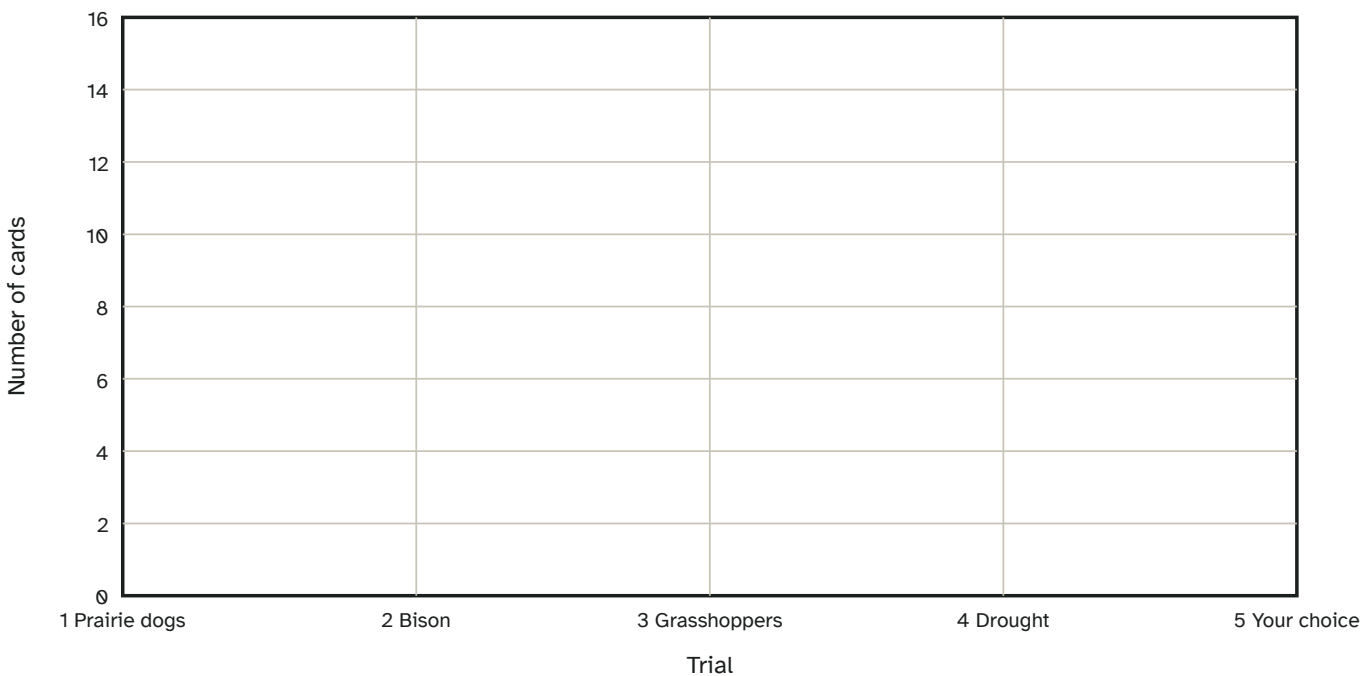
- In trial 3, the ferruginous hawks went DOWN even though hawks do not eat grasshoppers. Trace the chain, link by link, that reached the hawks.

Answer: Grasshoppers removed, so deer mice lose one of their three foods and go DOWN (wave 1). Hawks need deer mice as one of their foods, and a food that is DOWN makes the eater DOWN, so the hawks go DOWN (wave 2).

Why: This is an indirect effect: the hawks are two links from the grasshoppers, and the effect travels through a population they share.

Also acceptable: Rattlesnakes and coyotes follow the same chain and also go DOWN in wave 2.

Cards changed in each trial (draw two bars per trial: total changed and number LO



Check the model against the field

Burrowing owls on prairie dog colonies, Great Plains National Grasslands, spring and summer 1998

Kind of colony	Colonies surveyed	Colonies where burrowing owls were found
Active (prairie dogs present)	444	307
Inactive (prairie dogs gone because of plague, shooting or poisoning)	138	15

Real survey data from Sidle and others (2001), Journal of Raptor Research 35(4): 316-321.

Two more field findings. **1.** Black-footed ferrets get almost all of their food from prairie dogs and live in prairie dog burrows. By 1987 the last 18 known wild ferrets had been captured for captive breeding, and the ferrets living in the wild today come from captive-bred animals released onto prairie dog colonies. **2.** In a five-year experiment in a desert grassland, mesquite shrubs became three to five times more abundant in plots where prairie dogs had been removed than in plots where prairie dogs remained.

3. (a) Use the owl table to calculate the percent of active colonies and the percent of inactive colonies where burrowing owls were found. (b) Your model predicted burrowing owls are LOST when prairie dogs disappear. Does the field evidence agree completely, partly or not at all? Explain.

Answer: (a) Active colonies: $307 \div 444 = 0.691$, about 69 percent. Inactive colonies: $15 \div 138 = 0.109$, about 11 percent. (b) Partly. The direction agrees: owls were found on far fewer colonies after the prairie dogs were gone, roughly one sixth as often ($69 \div 11 \approx 6$). But the model said owls were LOST everywhere, and the survey still found owls on 15 inactive colonies, so the real effect is a large decline, not a total loss.

Why: Percent = colonies with owls $\div$ colonies surveyed $\times 100$. The point of part (b) is that the evidence supports the model's direction but not its all-or-nothing size.

- Both percentages correct (about 69 and 11)
- Says 'partly' and explains: same direction, but not a total loss

Analysis questions: answer key

4. Rank trials 1 to 4 from the most cards changed to the fewest, giving each total. How many times as many cards changed when prairie dogs were removed as when bison were removed?

Answer: Trial 4 drought: 14; trial 1 prairie dogs: 12; trial 3 grasshoppers: 7; trial 2 bison: 1. Removing prairie dogs changed $12 \div 1 = 12$ times as many cards as removing bison.

Why: Totals come from applying the rules (see the teacher notes for the full results). If a group's totals differ, check whether UP tokens were allowed to travel or whether the burrows card was missed.

Also acceptable: If a group counted the water card in the drought trial, accept 15 with that explanation.

5. Bison are by far the biggest animals in this model. Use your trial totals and the number of strings attached to each card to explain why prairie dogs, not bison, act as the **keystone species** here.

Answer: The bison card has one string (to grasses) and nothing in the model depends on bison, so removing them only let the grasses go UP: 1 card changed. The prairie dog card has 8 strings of four kinds (food for four predators, an eater of two plants, the clipper of shrubs, and the digger of the burrows), and it is a ★ **MUST HAVE** for the burrows and the ferrets. Removing prairie dogs changed 12 cards and caused 3 to be LOST, including the burrows that owls and cottontails need. A keystone species is one whose effect on the community is far larger than its size or numbers suggest, so the small prairie dog, not the large bison, is the keystone here.

Why: Students should use both measures: links (8 versus 1) and results (12 changed and 3 lost versus 1 changed and none lost). Size is a distractor.

- Compares string counts or links (8 versus 1)
- Compares trial results (12 versus 1, with losses)
- Defines keystone by the size of the effect, not the size of the animal

6. In trial 1, how many cards changed in wave 1, and how many changed only in later waves? Name the later-wave cards and write the chain that reached one of them, link by link.

Answer: Wave 1: 8 cards (grasses UP, wildflowers UP, shrubs UP, burrows LOST, ferrets LOST, rattlesnakes DOWN, coyotes DOWN, hawks DOWN). Later waves: 4 cards. Burrowing owls (LOST) and cottontails (DOWN) changed in wave 2; grasshoppers (UP) and deer mice (UP) changed in wave 3. Example chain: prairie dogs removed, so the burrows are no longer repaired and are LOST; burrowing owls lose their ★ shelter and are LOST; grasshoppers and deer mice lose a predator and go UP.

Why: The indirect effects all pass through the burrows card, a nonliving part maintained by a living one. $8 + 4 = 12$ changed.

- 8 in wave 1 and 4 later
- Names owls, cottontails, grasshoppers and deer mice
- A complete chain through the burrows

7. Trial 4 changed a nonliving part. Compare it with trial 1: which changed more cards, and which caused cards to be LOST? Use both results to argue whether a change to a physical component can affect populations as much as a change to a biological one.

Answer: The drought changed more cards (all 14 others went DOWN, compared with 12 for prairie dogs), but it caused no LOST cards, while removing prairie dogs caused 3 (burrows, ferrets, owls). So a physical change can reach every population, because every animal depends on plants and every plant depends on soil water. In this model the drought made populations smaller everywhere, while the keystone removal wiped out some populations and helped others. Both kinds of change can affect many populations; which is bigger depends on whether you count how many change or how severely they change. A drought so severe that the water card were LOST would make every card LOST.

Why: This is the PE's point that disruptions to physical or biological components can both shift populations. Full credit compares both measures (total changed and number lost).

- States 14 versus 12 changed and 0 versus 3 lost
- Explains why a change at the base reaches everything
- Concludes that physical changes can affect populations as much as biological ones, with a qualification

8. Find two places where the model and the real world probably disagree. (a) Compare the model's prediction for burrowing owls with the survey table. (b) In trial 1 the model says wildflowers go UP when prairie dogs are removed, but field surveys often find more wildflowers on prairie dog colonies, where digging and clipping open up space for them. For each, say what the model leaves out and how you would change a card or a rule.

Answer: (a) The model says owls are LOST, but owls were still found on 11 percent of inactive colonies, compared with 69 percent of active ones. The model leaves out other burrow diggers (ground squirrels, badgers), burrows that last for a while after the prairie dogs die, and owls moving in from nearby colonies. Change: make the owl's shelter 'burrows or other burrows (not in the model)' so losing prairie dog burrows gives DOWN, or add a 'strongly DOWN' token. (b) The model says wildflowers go UP because an eater is removed, but it leaves out the way prairie dog digging and clipping open bare soil and hold back grasses that compete with wildflowers. Change: add an orange 'opens space for' string from prairie dogs to wildflowers and a rule that losing a helper gives DOWN, so wildflowers would become MIXED, which matches the field evidence better.

Why: This is model evaluation: a model's predictions are tested against data, and mismatches show what to add. Accept any specific, sensible change to a card or a rule.

Also acceptable: For (b), accept adding competition between grasses and wildflowers (more grass means fewer wildflowers).

- Identifies the owl mismatch (lost versus 11 percent)
- Names something the model leaves out for each case
- Proposes a specific change to a card or a rule

9. Write a short argument using only the real survey data, not the model: does losing the prairie dogs from a colony affect the burrowing owls there? Give a claim, the numbers as evidence, the reasoning (a mechanism), and one limit of this evidence.

Answer: Model response: Claim: losing the prairie dogs from a colony greatly reduces the chance that burrowing owls live there. Evidence: in the 1998 survey of Great Plains National Grasslands, owls were found on 307 of 444 active colonies (about 69 percent) but on only 15 of 138 inactive colonies (about 11 percent), a pattern repeated across hundreds of colonies. Reasoning: on the Great Plains burrowing owls nest in burrows dug by prairie dogs; when the prairie dogs die, nobody repairs the burrows, so they cave in and the owls lose their nesting places. Limit: this is one season's with-and-without comparison, not before-and-after counts on the same colonies, and inactive colonies could differ in other ways; for example, poison used on prairie dogs could also harm owls, and the survey records whether owls were present, not how many.

Why: This is the PE as written: an argument supported by empirical evidence that a change to a biological component affected a population. It must use the real numbers, not the model's output.

- A claim about owls and prairie dog loss
- Both counts or percentages as evidence
- A mechanism (burrows as nesting sites)
- A real limit (one season, no before-and-after, other differences between colonies, presence not numbers)

Individual evidence of learning

Each student keeps their own trial table and graph and answers q1 to q9. The trial counts with the explanations in q4 to q7 show that the student can trace direct and indirect effects of physical and biological changes; q9, the argument from the real owl survey, is the individual evidence toward MS-LS2-4.

Assessment criteria

Criterion	Proficient looks like
Applying the model rules	Trial totals match the rules (12, 1, 7 and 14 cards changed), LOST cards are named, and the board is reset between trials.
Direct and indirect effects	Separates wave-1 changes from later waves and writes at least one complete chain that runs through a nonliving part (the burrows).
Keystone and physical-versus-biological reasoning	Uses string counts and trial totals to explain why prairie dogs act as a keystone, and compares the drought with a removal using both the total changed and the number lost.
Model versus evidence	Calculates both owl percentages, explains where the model's prediction fails and proposes a specific change, and writes a claim from the survey numbers with a mechanism and a limit.

Accessibility adaptations

- Standing-web option for students who need movement: each student holds three or four cards on a clipboard in a circle, the strings run between clipboards, and a removal is felt as a tug.
- For students who need more support, tape the strings ahead of time so the group starts with the rules; provide the rules as a flowchart with icons.
- Color-blind access: tag each string with a letter (F food, S shelter, W water, C clipping) as well as its color, and print L, D and U on the tokens.
- Provide a bilingual glossary (population, shelter, predator, prey, drought, burrow, colony) for multilingual learners, and allow q9 to be drafted orally first.
- For students with fine-motor difficulties, use a printed web map with the links drawn as lines and place tokens on the map instead of taping yarn.

Low-cost alternative

Skip the yarn: print the web as a map with the 32 links drawn as colored lines, and run the trials by placing tokens, or writing L, D and U in pencil, on the map. The reasoning and the counts are identical; only the tug is lost, and one printed map per group costs a few cents.

Model limitations

The model is far simpler than a prairie. It has 15 cards where a real shortgrass prairie has hundreds of species, and it treats every effect as the same size: losing one food out of three counts as the same DOWN as a near-total collapse. UP effects stop where they land, so the model cannot show more grass feeding more bison, and DOWN effects travel only to eaters and users, never to prey. It leaves out competition between plants, other burrow diggers such as ground squirrels and badgers, animals moving in from nearby colonies, time lags and recovery. The ★ links are deliberately strict, which is why the model predicts that burrowing owls are lost when the survey shows a large drop instead. The trial counts are model outputs, not measurements; only the owl survey and the two field findings are empirical evidence. This lab has not been physically tested with students, and the timing is an estimate.

Teacher notes

Results of every single change under the rules (total of the other 14 cards that change; LOST cards named). Prairie dogs: 12 (burrows, ferrets, owls LOST; cottontails, rattlesnakes, coyotes, hawks DOWN; grasses, wildflowers, shrubs, grasshoppers, deer mice UP). Burrows: 12 (prairie dogs, ferrets, owls LOST; the rest as for prairie dogs). Grasses: 11 (bison LOST; the other animals and the burrows DOWN). Wildflowers: 10 (all DOWN: burrows and every animal except bison). Grasshoppers: 7 (grasses and wildflowers UP; deer mice, owls, rattlesnakes, coyotes, hawks DOWN). Deer mice: 7 (grasses, wildflowers, grasshoppers UP; owls, rattlesnakes, coyotes, hawks DOWN). Cottontails: 5 (grasses, wildflowers UP; rattlesnakes, coyotes, hawks DOWN). Shrubs: 4 (cottontails, rattlesnakes, coyotes, hawks DOWN). Rattlesnakes, coyotes or hawks: 3 each (prairie dogs, cottontails, deer mice UP). Owls: 2 (grasshoppers, deer mice UP). Ferrets: 1 (prairie dogs UP). Bison: 1 (grasses UP). Drought (water DOWN): all 14 DOWN, none lost. No single removal produces a MIXED card under these rules; MIXED appears only if students add a helper link, as suggested in q8. Sources for the field section: Sidle, J. G., and others (2001), 'Occurrence of burrowing owls in black-tailed prairie dog colonies on Great Plains National Grasslands,' *Journal of Raptor Research* 35(4): 316-321 (582 colonies surveyed in 1998; owls on 307 of 444 active and 15 of 138 inactive colonies); U.S. Fish and Wildlife Service and National Park Service accounts of black-footed ferrets (prairie dogs make up most of their diet; the last 18 known wild ferrets were captured by 1987); Ponce-Guevara and others (2016), *PLoS ONE*, a five-year experiment in which mesquite was three to five times more abundant where prairie dogs were removed. The card details are simplified: real ferrets and owls are also eaten by coyotes, owls and badgers, and prairie dogs eat some shrubs and forbs as well as clipping them.