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| **Title of Unit** | Coevolution or Not? Crossbills, Squirrels, and Pinecones |
| **Date and**  **Location of SI** | Mountain West 2012 |
| **Unit Developers & Contact Information** | Laura Conner,  Susan Hester,  Anne-Marie Hoskinson,  Mary Beth Leigh,  Andy Martin,  Tom Powers |
| **Context** | *What kind of course is unit designed for?*  It was developed for students in an introductory evolution class, but would be appropriate for any introductory biology class in which coevolution is discussed. It could be adapted for use in a more advanced evolution class.  *How long is unit?*  50 minute class period  *When will the unit be used in the course?*  Students need background in mechanisms of natural selection, adaptations, two-species interaction |
| **Abstract**  (< 200 words) | This case reinforces the concept of coevolution and gives students practice with the analysis and interpretation of data. The case study is designed for a single 50-minute class period after students have completed a brief pre-class reading assignment introducing coevolution. Evidience for interactions among red squirrels (*Tamiasciurus hudsonicus*), red crossbills (*Loxia curvirostra*), and lodgepole pines (*Pinus contorta* v. *latifolia*) are analyzed. The case describing the interactions among these species invites students to answer three questions: 1) What is required for demonstrating coevolution? 2) What specific evidence supports the conclusion that that red squirrels, red crossbills, and lodgepole pines are coevolving (or not)? 3) Why does the evidence support coevolution? Learning outcomes: Interpret and draw graphs; Evaluate evidence about whether two species are coevolving; Make testable predictions based on the hypothesis that two species are coevolving. |
| **Rationale** | Ehrlich and Raven ([1964](#_ENREF_4)) coined the term coevolution to describe the close ecological and evolutionary relationship between butterflies and flowers. Coevolution occurs when two (or more) species in a community adapt to one (or more) traits of the other species in a sustained, reciprocal way over time. Coevolution has since been explored by ecologists and evolutionary biologists and there are many examples that illustrate the richness of the kinds of coevolution that have shaped populations and communities over evolutionary time, including the simultaneous, mutualistic rise of pollinating insects (Lepidoptera, Hymenoptera, Diptera) and flowering plants (Magnoliophyta) in the Jurassic and Triassic periods; host-parasite coevolution; and predator-prey relationships such as between cheetahs and gazelles and among crossbills, squirrels, and pinecones. This case study illustrates an example of predator-prey coevolution and asks learners to extend their thinking to diffuse coevolution ([among three or more species; Janzen 1980](#_ENREF_5)).  Novice learners can have many misconceptions ([Janzen 1980](#_ENREF_5)) or naïve conceptions about coevolution. One is about the nature of adaptation itself: to novices, adaptation sometimes confers an idea of flexibility and choice (agency) on the part of the species. Students need reminders of the biological definition of adaptation, both as a process (through means of natural and/or sexual selection) and as an outcome (a change in a functional trait’s allele frequency). Students also need practice examining data that reflect changes in trait or allele frequencies. In this jigsaw case study, students examine graphical evidence of species traits to formulate arguments and conclusions about coevolution.  Another naïve conception is that two – and only two – interacting species must necessarily adapt to traits in the other (e.g., if a predator gets faster, its prey will certainly get faster too). This case study helps students reformulate that conception in three ways: 1) by using a system of three interacting species, in which evidence shows only two of the three species are known to be coevolving, (2) asking students to graphically depict the evolutionary relationship, including its direction and 3) asking students to consider what kind of evidence they would need to conclude that interacting species are, in fact, coevolving.  Finally, students typically struggle with interpreting graphical data, an exercise that is at the heart of this case study. In order to identify the evolutionary relationship supported by each piece of evidence, students must (1) identify the dependent and independent variables; (2) determine the effect (if any) of the independent variable on the dependent variable and (3) evaluate whether this is evidence of an evolutionary relationship and, if so, the nature of that relationship. Distinguishing between the dependent and independent variables also serves to emphasize the directional nature of the evolutionary relationship. Students with less-developed data interpretation skills get the advantage of coaching by students with more-developed skills (and, if available near-peer student instructors/facilitators), while students with more-developed data interpretation skills will still receive the benefit of reinforcing coevolution concepts through data interpretation. |
| **Learning Goals:** what students will know, understand, and be able to do; includes content knowledge, attitudes, & skills | 1. Understand that species interact on an evolutionary time scale 2. Know that other organisms can be powerful agents of selection |
| **Learning Outcomes:** Student behaviors or performances that will indicate they have successfully accomplished the goals | 1. Define coevolution. 2. Identify types of evidence that would help determine whether two species are currently in a coevolutionary relationship. 3. Interpret and draw graphs. 4. Evaluate evidence about whether two species are coevolving. 5. Make testable predictions based on the hypothesis that two species are coevolving. 6. Predict the outcome of a perturbation to a coevolved system. |

**Teacher background:**

This case is built on the work of Benkman and others ([Benkman et al. 2001](#_ENREF_1), [Benkman et al. 2003](#_ENREF_2), [Benkman and Siepielski 2004](#_ENREF_3)) in the case of red squirrels (*Tamiasciurus hudsonicus*), red crossbills (*Loxia curvirostra*), and lodgepole pines (*Pinus contorta* v. *latifolia*). Both the squirrels and the birds predate lodgepole pine seeds. While crossbills have co-occurred within pine forests for thousands of years, red squirrels were absent from the same forest types for ~10kY, until they were reintroduced in ~1950 ([Benkman et al. 2001](#_ENREF_1)). The case describing the interactions among these species invites students to answer three questions:

1. What is required for demonstrating coevolution?
2. What specific evidence supports the conclusion that that red squirrels, red crossbills, and lodgepole pines are coevolving (or not)?
3. Why does the evidence support coevolution?

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| **Incorporation of Scientific Teaching Themes** | | |
| **Active Learning** | **Assessment** | **Diversity** |
| How students will engage actively in learning the concepts | How teachers will measure learning; how students will self-evaluate learning | How the unit is designed to include participants with a variety of experiences, abilities, and characteristics |
| *Activities outside of class:*  Pre-class reading on coevolution  *Activities in class/ Activities during tidbit*:   * Class discussion * Small Group data analysis/graph interpretation * Relationship map generation/graphical representation * Clicker Question * Individual data prediction | *Pre-assessments:*  None  *In class assessments:*  Formative:   * Group processing about presence/direction of interaction * Clicker question   *Post tidbit/class assessments:*  Homework or exam questions asking:   * Here are data for two species. Are they coevolving or not? Why? * Define and explain terms and concepts | * Video clip * Individual and group learning * Verbal, graphical, tactile information |

**Sample** Presentation Plan (general schedule with approximate timing for unit)

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| **Session 1** | | | | |
| **Time (min)** | Learning Outcome(s) | Activity/assessment | | Explanation, notes, suggestions, tips |
| *Preclass* | Define coevolution | Brief reading on coevolution | |  |
| *Introduction*  *10 minutes* | State conditions under which coevolution occurs | Lecture/class discussion | The instructor should review two necessary conditions for coevolution to occur: geographical overlap between species, and reciprocal change in traits. The instructor should briefly elucidate this definition, then invite students to view a video of a cheetah chasing a gazelle. Instructors can ask students to consider how co-evolution is shown in the video, and to consider what happens when cheetahs get faster. The instructor should ask students for their ideas. The fundamental concepts that students should notice are that speed is under strong directional selection in each species, and that the players themselves (populations of cheetahs and gazelles) are the selective agents for changes in this trait. Instructors should make sure to emphasize the *population-level* interaction between cheetahs and gazelles in this and future coevolutionary interactions. | |
| *Introducing the case study*  *7 minutes* |  | Lecture/class discussion | The instructor should invite students to consider a more complex system of 3 species: crossbills, squirrels, and lodgepole pine cones. After briefly describing the natural experiment that exists in the Rocky Mountains, the instructor should step through the plot/map handout and the relationship map handout with the entire class, clarifying the instructions about how the students should draw the arrows between species based on their evidence. | |
| *Group evaluation of evidence*  *10-15 minutes* | Interpret and draw graphs.  Evaluate evidence about whether two species are coevolving. | Case study: small group data analysis | | Students should divide into small groups of 3-5. Each group should get one of the three handouts (Exhibits 1-3) containing data supporting a directional interaction between 2 of the 3 species. A minimum of three groups is required so that each group can consider one data set. In a large class, multiple groups can receive the same data set.  Students are asked to work with the data and consider what the evidence shows. They will work with the relationship map and decide whether the data set they have been given (Exhibits 1, 2, and 3) indicates a relationship between any of the species. Each group will draw a directional arrow connecting the two species represented in their Exhibit, indicating which species is impacting the traits of the other.  During this time, the instructor and TAs/learning assistants should circulate among groups, asking and answering questions and gathering formative feedback about how the process is going.  The instructor should draw the relationship map on the board *without the arrow*s while the students are working on the task. |
| *Class discussion (10 minutes)* | Interpret and draw graphs  Evaluate evidence about whether two species are coevolving | Interactive discussion of group work and synthesis | | When the groups have finished examining their Exhibit and determining the relationship and direction of interaction, the instructor should invite a member of each group to draw an arrow on the map on the board, indicating which relationship their evidence supported. While the instructor displays each Exhibit in the accompanying PowerPoint slide, a member of each group should describe the relationship and what impact was found (e.g., “in areas where squirrels occurred, pine cones became…”). The instructor should guide the conversation as necessary, focusing on what the evidence shows, rather than on what could be assumed or inferred.  When the map is complete, there will be bidirectional arrows between pinecone and crossbill, but only a uni-directional arrow between squirrel and pinecone. |
| *Clicker question*  *3 minutes* | Evaluate evidence about whether two species are coevolving  Explain how data supports conclusions | Clicker question  Class discussion  Pair-wise discussion | | The instructor should ask the students to consider the completed relationship map and present the clicker question asking students to conclude which species have a coevolutionary relationship according to the data presented. If there is not agreement about the answer (b) after polling the students initially, the instructor can ask the students to turn to a neighbor and try to reach a consensus. The instructor should re-poll the students, then ask a volunteer to explain his or her reasoning for the answer (co-evolution requires reciprocal change in traits). |
| *Class discussion*  *5 mins* | Identify types of evidence that would help determine whether two species are currently in a coevolutionary relationship | Whole class interactive discussion | | The instructor then asks whether or not students can say for sure if the squirrels and the pinecones have a co-evolutionary relationship (no—there is no evidence to evaluate for whether the pinecones are impacting squirrel traits). The instructor can then lead students in a discussion about what kinds of evidence would be necessary to support a co-evolutionary relationship between squirrels and pinecones. |
| *Optional extension*  *10 minutes* | Make testable predictions based on the hypothesis that two species are coevolving | Individual graph generation-prediction  Class discussion | | The instructor can end here, or as an extension, could ask students to generate a graphical prediction based on the hypothesis that the evolution of squirrel jaw musculature has been affected by pinecones. After giving students a chance to generate their predictions, the instructor can call on some students to describe their predictions or draw them on the whiteboard and explain their reasoning. The instructor should then present evidence that squirrel jaw musculature has, in fact, been impacted by pinecones (Exhibit 4). |

*Add additional activities information as needed for the unit.*

Resources for Teaching the Unit

**Files**

Class presentation ppt

Teacher background and teaching notes

TT Framework

Exhibits 1-4 (data for analysis during the case study)

Plot map handout

Relationship map handout

Relationship map teacher KEY

Summative Assessment questions – homework or exams

Video of Cheetah and gazelle

**References (pdfs in folder)**

Benkman, C. W., W. C. Holimon, and J. W. Smith. 2001. The influence of a competitor on the geographic mosaic of coevolution between crossbills and lodgepole pine. Evolution **55**:282-294.

Benkman, C. W., T. L. Parchman, A. Favis, and A. M. Siepielski. 2003. Reciprocal selection causes a coevolutionary arms race between crossbills and lodgepole pine. The American Naturalist **162**:182-194.

Benkman, C. W. and A. M. Siepielski. 2004. A keystone selective agent? Pine squirrels and the frequency of serotiny in lodgepole pine. Ecology **85**:2082-2087.

Ehrlich, P. R. and P. H. Raven. 1964. Butterflies and plants: a study in coevolution. Evolution **18**:586-608.

Janzen, D. H. 1980. When is it coevolution? Evolution **34**:611-612.

Effectiveness of unit (if you have used it in your own teaching)

Acknowledgements

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