CAUGHT IN THE ACT : AGENTS OF EVOLUTIONARY CHANGE

(L'évolution en flagrant délit)

Par **Peter Woodruff**

Activité pédagogique réalisée au Champlain Regional College (Saint-Lambert)

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Note : La version française sera disponible prochainement dans la section «Trésors pédagogiques» du site Internet du Saut quantique (http://www.apsq.org/sautquantique).

ACTIVITY 9

CAUGHT IN THE ACT : AGENTS OF EVOLUTIONARY CHANGE[1]

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Presentation of the pedagogical activity

The target population:

This activity benefits students in any introductory biology course dealing with the main features of the theory of evolution, such as 101-NYA-05 in the CEGEP science program. In its present form it should work well with 6 to 10 groups of 3 to 4 members each. This range of 18 to 40 students could probably be extended with a few modifications.

Short description of the activity:

"Caught in the Act: Agents of Evolutionary Change" is an active in-class learning module which puts participants in the roles of evolutionary biologists investigating the relative contributions of genetic drift and selection. By recreating some thought-provoking current research (January, 2000) on Old World fruit flies recently introduced to the west coast of the Americas, students see that (micro) evolution can be observed in populations of higher organisms. They further their developing understanding of the agents of evolutionary change and experimental design by investigating whether the Old World latitudinal cline in size has become established in the Americas over the past twenty years.

Aided by a PowerPoint presentation (or overhead transparencies), the teacher introduces key points, stimulates class interactions and animates student groups wrestling with the issues and intricacies of the problem. Handouts facilitate group inquiry and class discussions. At one stage, student groups each measure coded photographic enlargements of fly wings. The data generated is best consolidated in a computer spreadsheet projected in front of the class. Consideration of the results leads to student-derived conclusions about evolutionary theory and experimental design.

Pedagogical objectives to be fulfilled by the students:

This activity enables students to grapple with and master the rather abstruse mechanisms behind evolutionary change. Discussing their relative contributions to evolution makes these agents of modification more than a bare list of abstract terms on a textbook page. Having to formulate an argument to support a contention that this or that agent is more or less important encourages collaborative group behavior while reinforcing the concepts. This way, students develop the necessary familiarity and understanding to apply their knowledge of these agents of change to a real world case where the "experimental" results are in doubt until the end. They are also shown how their own measurements could contribute to deciding the outcome.

This activity also provides a great forum in which to think about experimental design. What first starts off as a simple question, "Does the Old World cline in size become reestablished in the Americas?" instantly becomes challenging. What do we mean by size differences? How can we be sure that the differences are due to latitude and not handling or temperature, for example? Are the size differences really genetically based? How do you tell? What do

1. I would like to salute the personal insights provided by George Gilchrist, Chair of Biology, Clarkson University, senior author of the research paper which originally sparked this work. Also, I would like to gratefully acknowledge the contributions of my students, and those of participants in presentations of this activity at St. Lawrence University, Canton, New York (February, 2000), Southeast Missouri State University, Cape Girardeau, Missouri (at the LifeLines OnLine Faculty Workshop: Accessible, Investigative Case Based Biology, June 2000), and Beloit College, Beloit, Wisconsin (at The BioQUEST Workshop: Developing Curricular Resources and Strategies for Introductory Science Courses, June, 2000). I have been assured that several of these participants will be using "Caught in the Act" this year at their respective colleges and universities.

we actually measure in the first place? The answers to these and other questions that inevitably arise make for lively discussion.

For many of our students, evolution is either too abstract or too loaded a concept to examine closely. For those who prefer to ignore its abstraction, this activity provides a concrete example of evolution in action. For those whose upbringing or personal search has left them fearing or distrusting the word "evolution", the gently forced contemplation of this non-threatening, concrete example may open the way for further consideration of the concept of evolution.

"Caught in the Act" also shows that biologists today are discovering new and intriguing facts about evolution. Evolutionary theory did not stop with Darwin. In a world of microcircuits and microarrays, scientific interest in the intricacies of evolution remains strong.

Part of a sidebar to this case could, and probably should, include reference to this year's "completion" of the *Drosophila melanogaster* genome and related attempts to examine evolutionary change by using modern tools of molecular biology and bioinformatics. Here is a prime opportunity to tie together the molecular, organismal and evolutionary realms of biology.

Relevance and originality of the activity:

"Caught in the Act" is an exciting, original way to introduce students to elements of evolutionary biology and experimental design. It encourages students to consider the details of an authentic research effort in light of its broader theoretical background. The seamless progression from theory to hands-on measurement bridges the divide between lecture and laboratory.

By identifying groundbreaking current research and building a hands-on activity around it, the author demystifies the workings of science. This one activity incorporates most of the "buts de programme" to accomplish this goal.

Link between the activity and the students' program

General objectives of the program that the activity helps to reach:

This broadly based activity helps science students attain many of the general goals of the science program. It directly reflects the Ministry's title for 101-NYA-05: Evolution and Diversity of Life. More specifically, it includes:

1. *Application of scientific method:* It presents an example of science in action. In the "3Ps" terminology promoted by the BioQUEST Educational Consortium[2], it provides a context in which to pose a problem and an opportunity to probe the problem for solutions. The class discussions encourage participation in *persuading peers* of the validity of each student's arguments.
2. *Solving problems in a systematic fashion:* It encourages students to attempt systematic problem solving in a subject area, namely evolutionary biology, which is rarely presented in this way to students at the introductory level.
3. *Using appropriate technologies in the handling of data or information:* There is a limited but dramatic use of spreadsheet data recording and manipulation in this activity.
4. *Reasoning with rigor:* Examples of tight reasoning are presented and employed in this activity.
5. *Working in groups:* Two rounds of group work are part of this activity.
6. *Establishing the connections between science, technology and the societal development:* Darwin and Wallace shook society to the core in the latter half of the 19th century. Evolution is arguably the scientific concept that has had the most impact on society[3]. This activity shows that evolutionary theory continues to develop today.

2. BioQUEST reference: see http://www.bioquest.org/ or The BioQUEST Library V (CD-ROM), Academic Press, 1998-99.
3. E. Mayr, "Darwin's Influence on Modern Thought", Scientific American, July, 2000.

7. *Understanding the context for the origin and elaboration of scientific concepts:* By examining a particular example of research on evolutionary theory, this activity exposes students to the continued elaboration of a key scientific concept.

8. *Adopting the scientific attitude to problem solving:* By showing examples of evolution in action, this activity should help students who may otherwise be too uneasy about evolution to see its relevance today.

9. *Using prior learning in novel situations:* This activity shows students that organisms that they will have seen at home or in the lab (fruit flies) serve in intense, on-going research across much of biology. They take newly acquired theoretical knowledge of the agents of evolutionary change and use them in a specific situation.

Links with the course in which the activity takes place:

Evolutionary theory forms a cornerstone of modern biological sciences. This activity helps students make evolutionary theory tangible, approachable and current. It fits naturally into the course after the usual presentation on Darwin and Wallace.

Links with other courses:

Developing "Caught in the Act" was one way to realize active science learning within a lecture format. I envision several companion activities in this and other courses based upon this approach.

Elements of the entrance or exit profile of the students related to the activity:

As the student entrance and exit profile is really a local expression of the program objectives, this item has been dealt with elsewhere.

Description of the necessary of supplied material

Teacher's material

A.1 PowerPoint presentation "CAUGHT IN THE ACT APSQ 01" or equivalent set of overhead transparencies (only in Internet site of Saut quantique, section « Trésors pédagogiques »)

A.2 Wing Size Collection Form – Excel document on computer or hard copy

A.3 "Rapid Evolution of a Geographical Cline in an Introduced Fly", R.B. Huey, G.W. Gilchrist, M.L.Carlson, D.Berrigan, & L. Serra, Science 287 (5451)(14 Jan 2000): pp.308-309. (in CD-ROM only)

Students' material

B.1 Agents of Evolutionary Change Ranking Sheet. Handout, 1 per student

B.2 Handout: Selected Studies of Evolution in Action. Handout, 1 per student

B.3 A manila envelope for each group, containing:

- Two different 8.5 x 11 inch sheets each showing 9 fly wing images. Each sheet portrays wings from a particular location. They are identified by student group and a coded location but not by latitude. The teacher should assemble these envelopes from the complete collection of FlyWing photographs in Appendix B.3.1.

  Note that the relative size of the average fly wing on each sheet is indicated by its number: Thus, "wing set 97-3b.gif" is 97% of "wing set 100-2a.gif". In each case the grouped number and sample letter is also indicated: "3b" is short for group 3, sample b.
- A small plastic metric ruler
- (optional) attached to the outside of the envelope: a small sheet with a blank table for recording wing sizes (see "B.3.2 Wing Length Record")

B.4 "What Have We Learned?" Handout, 1 per student.

Pedagogical framework

Teacher's role

As indicated, the teacher must flexibly move between the roles of lecturer and facilitator.

Organization of the activity

This activity takes about 75 to 90 minutes to complete. The exact timing and duration of each step will depend upon the size and composition of the class and the amount and nature of the discussion which surfaces.

Carrying out the activity

Required preparation time (teacher and students):

Once the materials are assembled and duplicated, there is little extra preparation time for the teacher. Students will have been introduced to the agents of evolutionary change in the previous lecture. They should be directed to read their textbook (or a handout) on the subject prior to the activity. This should take no more than 20 minutes.

Description of the activity's steps:

Slide 2.

Typically, the "Caught in the Act" activity would follow a general introduction to evolution and evolutionary theory. Though not absolutely required, a prior understanding of the Hardy-Weinberg equilibrium and an overview of the main agents of evolutionary change would be valuable.

With this slide, participants are informed that the activity will delve into the relative impact of these agents of evolutionary change. Starting with a discussion of the broad implications of these agents, students will focus in on specific instances of evolution in action. The class will be asked to consider how one would investigate this question through an "evolution experiment".

Slides 3-11

Drawing upon the students' prior knowledge and textbook reading, the teacher first reviews the main agents of evolutionary change: mutation, gene flow, nonrandom mating, genetic drift and selection.

Slides 12-13

The teacher asks the class to form groups to rank these agents in terms of their impact on evolution.

Here is where I distribute the "B.1 Agents of Evolutionary Change" handout. Groups of 3 to 5 students are asked to rank them on a 1 to 5 scale according to their relative impact on evolution. To build upon the students' understanding of the Hardy-Weinberg equilibrium, large and small populations should be considered separately.

Slide 13 provides a backdrop for the teacher to quickly describe how to fill out the handout. By considering each of the five agents listed under small and large population conditions, each group grapples with a wide variety of issues related to evolutionary change. In my experience, this leads to vigorous debate among the participants.

The ensuing class discussion should prove frustratingly theoretical.

Slides 14-20

To help resolve the problem and use the frustration positively, the teacher asks, "How might we actually determine the relative contribution of these agents to evolution?"

These slides help guide discussion through consideration of theoretical models and practical experiments. These experiments generally fall into three categories: laboratory, field and "natural". Most such experiments require following populations for many generations. Due to time constraints, many otherwise desirable experiments would be virtually impossible to perform.

Perhaps with the teacher's help, discussion leads to the evolutionary biologist's ace in the hole: the "natural experiment".

Slide 21

The discussion of the "natural experiment" should include conventional references to the concepts of cline and introduced species, which will prove valuable later in the exercise. If there is time, it would be useful to project textbook or other examples of clines and introduced species. These topics deserve their own detailed development.

Populations often respond to environmental gradients by forming clines, which provide natural, ongoing natural experiments.

The suitability of *introduced species* for research is often enhanced by their potential for severe economic and ecological impact upon indigenous or cultivated ecosystems. These conditions may also free up funding otherwise hard to get. Specific examples drawn from, or familiar to, the students could be developed here.

Slide 22

This slide brings the stars of the show on stage. Here are two female European fruit flies. Ask the students what they can say about them.

I reply to their feedback by saying, "Yes, the one on the right is larger. It is from Denmark. The one on the left is from Spain. Do you think that this is just a sampling artifact or is it part of an overall pattern? How could we tell?

First we had better know where they live.

Slide 23

Here is the worldwide distribution of *Drosophila subobscura* as it was in 1960. It lived around the Mediterranean (no, it is NOT a medfly), the Black Sea and north across most of Europe into Scandinavia.

Now, how do we tell whether our two flies are representative?

Measure many flies from known locations across Europe.

How might we measure the flies? It is not that simple. Encourage class discussion (See the comments for slides 25-30 below for some ideas).

Slide 24

After all this, the data are in. Those pictured flies are indeed representative of a cline in European fruit fly body size.

What can we learn from this graph?

Although their absolute sizes are different, the pattern for males and females is much the same: whatever is happening is happening to both sexes.

The differences are fairly subtle (note the limited range of sizes plotted, with no zero on the scale.). The tight error bars indicate that, all else being equal, the data should be reliable.

Slides 25 - 30

What about the "natural experiment" we were promised? Let us fast forward twenty years. What has happened to the distribution?

Clearly, slide 25 shows that the flies have spread to the West Coast of the Americas. Apparently a single ship brought a small but vital group of accidental colonists to California and Chile. They thrived. Their latitudinal range is now as great as it was in Europe. They elbowed out the indigenous flies: it is estimated that 90% of the fruit flies in Bill Gates' back yard are Drosophila subobscura. And they continue to move east…

What questions could be considered?

One might be: is the ancestral latitudinal cline evident in the Americas? Another might involve the effect(s) of altitude on body form.

It turns out that data collected ten years after the arrival showed no cline.

The data we have are not coded by altitude, although it might prove to be an interesting variable to discuss.

Now data collected twenty years after the arrival have been collected. What might they show?

Let us limit ourselves to genetic drift and natural selection. The other agents either do not apply (gene flow, assuming no interspecific hybrids are formed, and nonrandom mating) or occur at relatively low rates under most circumstances (mutation).

Encourage students or student groups to consider these questions:

If selection predominates, what results would we expect from sampling flies from across the range?

Assuming the European cline is adaptive, it might be expected to resurface in North America.

If genetic drift predominates, what results would we expect from sampling flies from across the range?

Wing size is less likely to vary directly with latitude.

Students are asked to predict the answer depending upon whether selection or genetic drift holds greatest sway. Considerable discussion ensues about how to compare the flies from different regions without bias. How to conveniently measure subtle size differences among minute fruit flies is also an issue.

Drying out can alter weight and distort body parts such as the abdomen. Three-dimensional parts suffer orientation problems: how do you consistently measure legs or abdomens which may be slightly twisted?

How about using wing size? Wings show readily identifiable landmarks and are essentially planar, reducing the orientation problem.

What about collection problems? Field-caught flies may differ in all manner of uncontrolled ways: diet, temperature, age, health, degree of damage from living or handling to name a few.

What about storage problems? Flies may be damaged in storage or suffer from dehydration, mold etc.

One way to offset many of these difficulties is to collect live flies at each location and bring them back to a common facility where they can be reared in separate but identical containers for several (say 5) generations under controlled conditions. Then flies of the same age can be measured and compared. Whew!

Through class discussion, this seemingly simple question reveals these and other traps for the unwary investigator. After identifying and avoiding pitfalls in experimental design, the students break into groups once more to actually measure flies from different sites.

Slide 31

Hand out manila envelopes, one per group of three to five students.

Each envelope contains:

- Two different 8.5 x 11 inch sheets each showing 9 fly wing images. Each sheet portrays wings from a particular location. They are identified by student group and a coded location but not by latitude.
- A small plastic metric ruler
- (optional) attached to the outside of the envelope: a small sheet with a blank table for recording wing sizes (see "B.3.2 Wing Length Record")
- (optional) One might add a line map of western North America, indicating latitudes and key locations, or project one during the exercise.

Ask students to assign someone to measure the wings, someone to record the measurements and someone else to enter the data into the spreadsheet on the computer (if available).

Their data are entered into an electronic spreadsheet. Ideally the spreadsheet would be projected for all to see. It is manipulated to reveal the relationship of average wing size to latitude.

Slide 32

Ask the students to consider what to measure.

As shown on the slide, measure the straight-line distance between the arrowheads.

Given the large number of untrained participants, develop the importance of adhering to a Standard Operating Procedure which specifies in no uncertain terms just how to perform each step.

Ask the class whether it would be appropriate for different members of each group to share the measuring function.

No, a single individual will probably show less variation within their measurements than two or more individuals sharing the work.

Point out that the coded pictures of the wings are not identified by latitude. Ask the class to consider whether this might reduce experimenter measurement bias. Is this a "blind" experiment?

Student groups are provided with two different samples of 9 wings each. This shows them that the wings in different samples are indeed different.

Circulate throughout the class while the students are measuring.

Have the students enter their data into the spreadsheet (A.2 Wing Size Collection Form) on a first-come basis.

If possible, the spreadsheet is projected for all to see. While the data are entered, no latitudinal information is visible; it is actually just off the screen in a column on its own.

The table automatically calculates the average wing size for each row or latitude. After the last group enters their data, the teacher can bring the latitude column into view and sort the table by latitude.

Several different ways to end this exercise should be considered, depending upon instructor preference and time constraints.

One route would be to have the spreadsheet program convert the student-derived data into a graph comparable to slide 24. Then slide 24 could be reintroduced and the two graphs compared.

Alternatively, class data could be distributed or emailed to students, who could then analyze it at their leisure.

Slide 34

It is problematic as to whether to show this slide to students. Some instructors may feel that the student data alone is sufficient.

In any case, their data will resemble those of Huey et al., on this slide. This graph combines the European data presented before with data from the North American flies. The overall pattern for both continents is much the same, especially for the females.

Whether one uses only the student data or brings in the Huey et al data, one must review the results with the students

The results show that ancestral cline in size has been reestablished in North America. Vancouver flies are indeed larger than their San Diego counterparts. This provides concrete evidence that selection, rather than genetic drift, plays the dominant role in the evolution of body size in this population.

Slide 35

As an optional footnote:

One might ask whether the European and North American fly populations establish their latitudinal clines through the same genetic mechanism.

It appears that there are differences:

One can divide the total wing length into different portions (equivalent to measuring upper arm and forearm distances as parts of total arm length in humans). Although the overall size of the flies' wings increased with latitude in both N. American and European populations, Huey et al found that the proportion of the wing length provided by the basal section of the wing increased in the European flies but decreased in the North American flies (see figure).

Slide 36

To wrap up and reinforce the experience, students use a review handout sheet (B.4 What Have We Learned?) to summarize their new understanding of experimental design and evolution. Time constraints may make this a homework assignment. Teachers should guide the students' responses, especially to the second part.

The handout, "B.2 Studies-Evolution in Action", summarizing two such natural experiments could be distributed for future reading.

Suggested assessment for the activity

Although the review handout sheet could be used as an assessment, it is probably preferable to include an item on this material on the next term test or as an exercise in a subsequent class. Regular multiple choice questions might be used but education theory suggests that it would be preferable to ask a question that more closely follows the original activity.

For instance, here is a question that could be given the week following the activity. Students would be given a brief summary of a piece of evolutionary research and be asked for their feedback on experimental design and evolutionary change agents. This example is a modified summary of some work by Jonathan Losos published in Nature in 1997.

Question:

> Fourteen years ago, evolutionary biologists transplanted small populations of tree-dwelling Anolis sagrei lizards from Staniel Cay in the Bahamas to 14 nearby tiny islands, all of which had been lizard-free. Staniel Cay is covered with forest, whereas most of the smaller islands mentioned have few or no trees. The researchers expected the reptiles to go extinct, but by 10 to 14 years later, the animals appeared to be undergoing the kind of body changes that in time could turn each island's population into a separate species. If the changes were genetic, the study would be strong evidence that isolated populations diverge by natural selection, not by genetic drift, as some theorists have argued.

Use your understanding of genetics and the agents of evolutionary change to answer the following:

> The researchers are using hind limb length as an indicator of evolutionary change. They are looking for different degrees of limb lengthening or shortening. What sort of pattern of change in limb length would you expect on the different islands if genetic drift has been the predominant agent of evolutionary change at work on these lizards. Support you answer by briefly explaining the nature of genetic drift.
>
> > <Suggested answer: With genetic drift "in charge", lizard populations on the various islands would be expected to reflect the lengths of the small populations first moved to each island. They would probably vary somewhat from the parental population in a more or less random fashion. See your text for a definition of genetic drift.>
>
> What sort of pattern of change in limb length would you expect on the different islands if selection has been the predominant agent of evolutionary change at work on these lizards. Support you answer by briefly explaining the nature of selection.
>
> > < Suggested answer: With selection "in charge", lizard populations on the various islands would be expected to adapt in various ways to the new conditions. If shorter legs suit a treeless environment, there should be selection for shorter legs in the lizard population. Over time the average leg length should become less. See your text for a definition of selection.>
>
> How might the researcher determine whether the changes are genetic?
>
> > <Suggested answer: Collect lizards from various islands, including Staniel Cay, and breed them for several generations under common, controlled conditions. If, after that time, the length differences are preserved, the leg length change is likely to have been genetic.>

This sort of question asks the students to apply their knowledge to a new, but related, situation. Though challenging, it grows directly out of the students' experiences in class. Exact mark values are rather meaningless here, but it should have a substantial influence on the grade for this part of the course.

7. References

Balanya, J; Segarra, C; Prevosti, A; Serra, L. (1994) Colonization of America by *Drosophila subobscura:* The founder event and a rapid expansion. Journal of Heredity, v.85, n.6, 427-432.

BioQUEST reference: see http://www.bioquest.org/ or The BioQUEST Library V (CD-ROM), Academic Press, 1998-99.

Bryant, P.J., Pattern formation in imaginal discs. Ashburner, Wright, 1978-1980 1978 c:230-335. See http://flybase.bio.indiana.edu/.bin/fbidq.html FBim1610599.

Huey, R.B., G.W. Gilchrist, M.L.Carlson, D.Berrigan, & L. Serra, "Rapid Evolution of a Geographical Cline in an Introduced Fly", Science 287 (5451)(14 Jan 2000): 308-309.

Losos, J.B., Jackman, T.R., Larson, A., Queiroz, K. d, Rodriguez-Schettino, L. "Contingency and Determinism in Replicated Adaptive Radiations of Island Lizards" Science 279 (5359) (27 Mar 1998): 2115-2118,

Misra, R. K., and E. C. R. Reeve. (1964) Clines in body dimensions in populations of Drosophila subobscura. Genetical Research 5:240-254.

E. Mayr, "Darwin's Influence on Modern Thought", Scientific American, July, 2000, volume 283: pp. 79-83.

Rodríguez-Trelles, F., M. A. Rodríguez, and S. M. Scheiner, Tracking the genetic effects of global warming: Drosophila and other model systems, Conservation Ecology 2(2):2
http://www.consecol.org/vol2/iss2/art2

Pennisi, E., "EVOLUTION: Nature Steers a Predictable Course", Science 287 (5451)(14 Jan 2000): 207-209,

Prevosti, A., G. Ribó, L. Serra, M. Aguadé, J. Balaña, M. Monclús, and F. Mestres. (1988) Colonization of America by Drosophila subobscura: experiment in natural populations that supports the adaptive role of chromosomal-inversion polymorphism. Proceedings of the National Academy of Sciences (USA) 85:5597-5600.

Weiner, J. (1994), The Beak of the Finch: A Story of Evolution in Our Time, Vintage, New York.

Appendicies

A.1 CAUGHT IN THE ACT APSQ 01 (Annotated PowerPoint Presentation)

A.2 Wing Size Collection Form (Excel Spreadsheet) (ONLY on CD-ROM, available from the author)

A.3 Flies article: "Rapid Evolution of a Geographical Cline in an Introduced Fly", R.B. Huey, G.W. Gilchrist, M.L.Carlson, D.Berrigan, & L. Serra, Science 287 (5451)(14 Jan 2000): pp.308-309. (ONLY on CD-ROM).

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B.1 AGENTS RANKING SHEET

B.2 Studies-Evolution in Action

B.3.1 FlyWing GIFs (also available as JPEGs, contact author)

B.3.2 Wing Length Record

B.4 What Have We Learned?