Image courtesy of Michael Apel / Wikimedia Commons

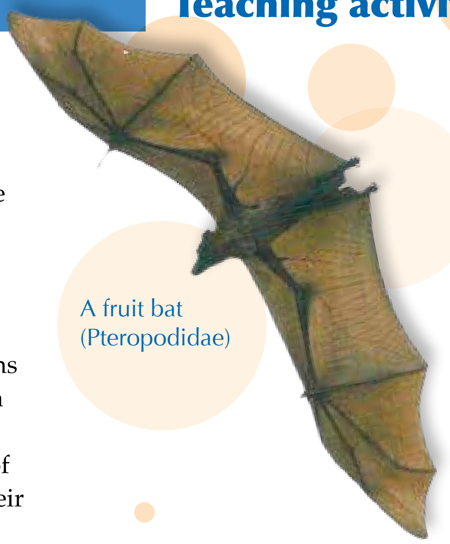
Juvenile male damselfly (*Calopteryx virgo*)

Phylogenetics of man-made objects: simulating evolution in the classroom

Image courtesy of kevincole / Wikimedia Commons

American avocet (*Recurvirostra americana*)

Evolutionary relationships can be tricky to explain. By using simple, everyday objects, your students can work them out for themselves.



A fruit bat (Pteropodidae)

Image courtesy of Peter van der Sluijs / Wikimedia Commons

By John Barker and Judith Philip

Birds, bats and insects all have wings; horses, millipedes and crocodiles all have legs. Many unrelated species can be grouped by physical similarities – that is one of the problems with studying morphological phenotype to determine evolutionary relationships. Convergent evolution can result in apparently similar structures. Although the end product may be the same (e.g. the presence of wings), the starting points can be very different. Some organisms that may appear similar and hence related are actually widely separated from each other in the evolutionary tree.

At a molecular level, DNA and protein studies can be used to produce a family tree by looking at the differences between homologous sequences: sequences that are thought to have evolved from a common ancestor. Kozlowski (2010) describes an excellent activity to demonstrate this in a classroom, but there is a sense of being removed from the study – the data required is simply downloaded and used. This article provides a complementary, more hand-on introduction to evolutionary studies, in which the students gather all the necessary data themselves before considering the underlying principles.

In this classroom activity, your students can use a wide range of objects to create an artificial phylogeny based on morphology. The family tree that they produce will be artificial in the sense that the objects used have not actually evolved from each other. However, the problems faced and the questions posed are similar to those addressed by palaeontologists using specimens of fossils, or by entomologists using specimens of dead insects in museum cabinets.

The activity, which takes approximately 30 minutes, is suitable for a wide range of students, from the age of about 15 up to postgraduate level.

It allows students to:

1. Use morphology to make an 'evolutionary' tree.
2. Link morphology to adaptations and consider the definition of a species.
3. Hypothesise the morphology of missing links and state how their hypothesis could be tested.
4. Consider the challenges and limitations of using evolutionary trees based on morphology and on DNA sequences.
5. Investigate for themselves the concepts of divergent, convergent and parallel evolution.
6. Present, discuss, defend and evaluate a proposed evolutionary tree.
7. Recognise the expertise required by scientists when making evolutionary trees.

REVIEW

- Biology
- Evolution
- Ages 14-19

Evolution is a tricky concept to understand. This article describes an unusual but simple classroom activity, using cheap and easily available materials to teach some of the most basic principles of evolution. More specifically, through the use of evolutionary trees, students can investigate the phenomena of divergence, convergence and parallel evolution. It's also fun!

Michalis Hadjimarcou, Cyprus

Guiding principles

There are four guiding principles used to produce an evolutionary tree based on morphology:

1. Organisms that resemble each other in many ways are probably more closely related than are organisms that resemble each other only slightly. That is, the greater the similarity in structure (the more features in common), the closer the probable relationship between two forms.
2. Evolution is usually the result of a gradual accumulation of small changes in structure (and function) but occasionally there are larger changes.
3. In general, simpler forms give rise to more complex ones and smaller forms to larger ones, although there can be exceptions.
4. Evolutionary processes do not go into reverse, but specialised structures can be lost.

Activity: evolution in the classroom

One version of this activity uses metal objects such as nails, screws, staples, paperclips and drawing pins. The greater the number of objects used, the longer the activity will take.

As a guide, it will take the students around 15 minutes to sort out the evolutionary relationships and 10-15 minutes for feedback and discussion. The time required could be shortened by using fewer objects or using

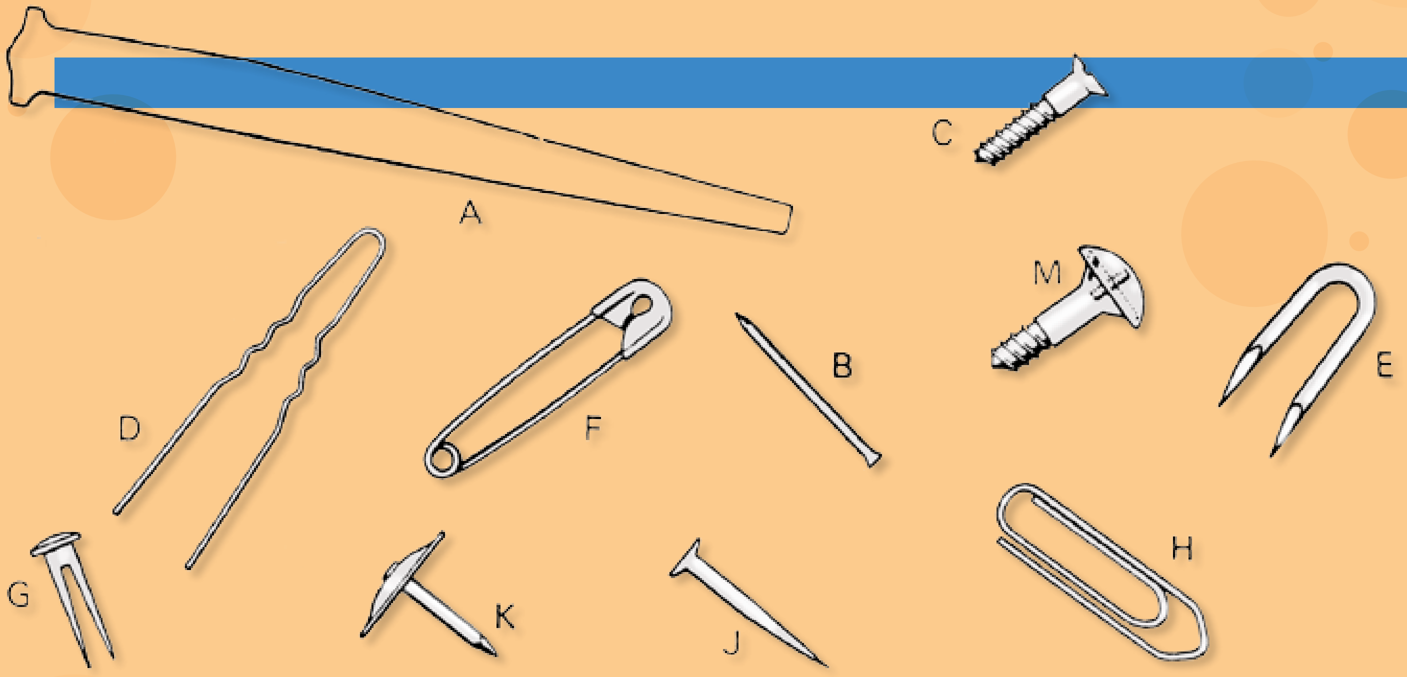


Image courtesy of John Barker

printouts instead of real objects – although it is more fun to handle real objects.

Materials

For each group, you will need one example each of some or all of the following metal objects (figure 1). Alternatively, you can use printouts of the objects (see the procedure, below).

- 75 mm tack [A]
- 20 mm nail [B]
- 20 mm screw [C]
- Hairpin (50 mm) [D]
- Staple (25 mm) [E]
- Safety pin (40 mm) [F]
- Split rivet (20 mm) [G]
- Paperclip (32 mm) [H]
- 25 mm tack [J]
- Upholstery pin (20 mm) [K]
- 13 mm nail [L]
- Mirror screw (20 mm) [M]
- Insulated staple (13 mm) [N]
- Round-headed paper fastener (20 mm) [O]
- Flat-headed paper fastener (20 mm) [P]
- Round-headed screw (25 mm) [Q]
- 50 mm nail [R]
- Drawing pin (6 mm) [S]
- Hook (20 mm) [T]
- Kirby grip [W]
- Bolt (65 mm) [Z]

Note, however, that it is not essential that the objects are exactly the size stated.

Procedure

1. Divide the class into groups.
2. Either:

a) Hand out one of each of the objects shown in the figure to every group. Make sure each object has a letter.

b) Download the pictures of the objects in figure 1 from the *Science in School* website[w1] and cut them out, keeping the letter with the picture. Use the printouts as though they were the actual objects.

3. Ask your students to arrange the objects to form a possible evolutionary series, using the four guiding principles. Encourage them to choose the smallest, simplest form as the probable common ancestor for the group and then try to arrange the others as branches of a tree derived from this ancestor.
4. Ask your students to record their trees using the letters associated with the objects.
5. Explain the concepts of divergent, convergent and parallel evolution. Then get your students to mark their trees to show possible divergence, convergence or parallel evolutionary developments.

Some solutions and discussion points

Some lines of evolution seem very obvious whereas other specimens will be quite difficult to place. Some may fit in several positions.

- The common ancestor is probably L — a small, simple form with a tiny head and simple shaft.
- L → B → R is an obvious line showing increase in size.
- L → J → A is a parallel line with a square shaft and larger head between Land J. L or B or J could have → C by an increase in complexity of head and shaft. (L or B seems the more likely ancestor because J has a square shaft.)
- C → Q → Z is a line showing an increase in size, increase in complexity of head, and finally a change in the shaft. Probably C → T through a change in head accompanied by slimming of the body.
- L → S → K is a line showing an increase in size and specialisation of the head. Probably S → P through an increase in size, but the material is different so it is possible that B or J → P, in which case there would be a convergence between P and S / K.
- Is G part of this evolutionary series? Either S or P could → G by a thickening and subsequent splitting

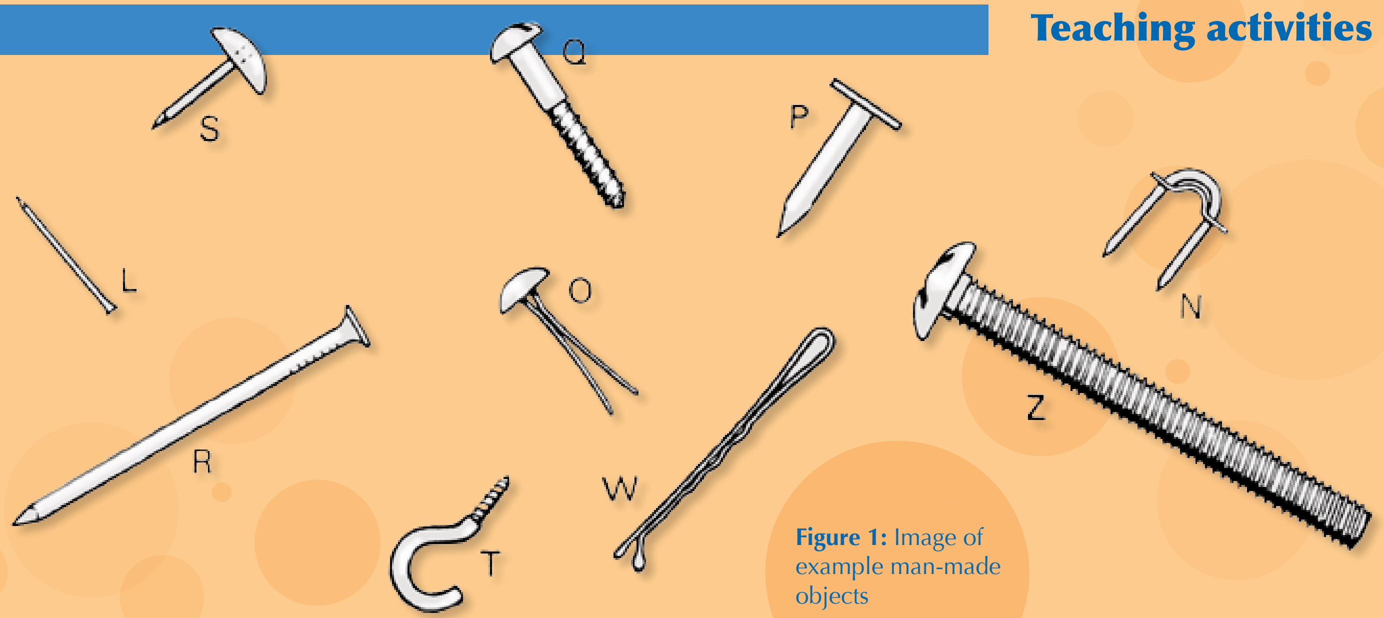


Figure 1: Image of example man-made objects

of the shaft. Probably G → O by a combination of elongation and slimming (a sort of eel-like series).

- M presents an interesting problem: of its two parts, one, the base component, is clearly very close to C in structure; the other part, the top component, shows similarities to Z but the head is smooth, not grooved. M also shows similarities to S but the shaft is threaded, not smooth. This is probably part of the radiation from C but it is clearly convergent to S. Do the two components represent two sexes (illustrating sexual dimorphism) or is M really a curious hybrid between descendants of C and S?

All the evolutionary series considered so far basically have a straight shaft and a single axis (exceptions are G and O where the shaft is double; T, which has a curved head, is another highly divergent type). We could say that all these forms are members of a single order – Orthos (from the Greek for 'straight') or some similar name. The rest of the objects are bent in various ways – Sinuos (from the Latin for 'curve') or some similar name. Of the curved objects, the simplest form is probably E so this is likely to be nearest to the common ancestor.

- Probably L → E by loss of its tiny head and bending of the shaft but it is just conceivable that T → E by loss of the screw thread and further bending of the head. It seems more likely that T is convergent to the series descended from E.
- E → N by addition of the plastic insulation.
- E → D by elongation and slimming of the two sides and appearance of waves.
- D → W by further asymmetrical specialisation of the two sides.
- H and F look as though they are related, with H → F by addition of material to form a head. H might be derived from E by slimming and bending, possibly with common ancestry with D; extra bends formed later, thus E → X (not represented in the collection – an as yet undiscovered fossil) → D → W and X → H → F.
- G and O have double shafts – could they be part of the Sinuos order? O could be derived from E by slimming and development of the centre into a sort of head, and then O could develop into G by strengthening and solidification. In this case, there would be strong convergence between G and S / P.

Within each 'order', there are several divergent lines. Series showing increases in size are common in the Orthos group; they also show variety in the development of the head and of the shaft, both independently and together. The Sinuos group shows variety in the bending of the two shafts; they generally lack heads – which may make it more probable that G and O are Orthos and not Sinuos.

Your students may have thought out quite a different series of evolutionary lines but as long as they can justify them using the four general principles, then each series is just as credible. If the objects were extant organisms, then there would be other possible lines of argument – such as studies of their molecular characteristics or of their embryology – which might support some hypotheses while discounting others and so indicate more precisely the probable evolutionary series.

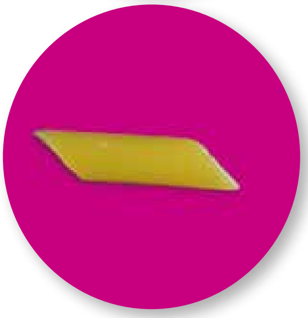
Variations

This type of activity can also be carried out with a range of other objects, for example biscuits or dried pasta. These materials can introduce another variable – that of colour. Do the colour differences represent camouflage, for example, or sexual dimorphism?

For a simple, 20-minute activity, a small group of objects can be used to represent the problems sometimes faced by palaeontologists. New specimens can be introduced as if they were recently discovered fossils. How can these new finds be accommodated in the tree?

Images courtesy of Isabelle Kling



Once your students have completed their trees, it is useful for them to assess each other's work. For example, they could ask:

1. Why have you put XX at the start of your tree?
2. Do you think YY evolved before ZZ?
3. Why (not)?
4. Do you think different coloured versions of the same shape are the same or different species?
5. Why (not)?

Have any groups of students produced identical trees? Can each group justify their reasons for choosing particular evolutionary pathways? This could lead to a discussion of why it is very difficult to generate an undisputed 'correct' tree. The students can then start to appreciate the depth and range of expertise that is required by an evolutionary biologist.

Next, tell your students that the pasta shapes (or biscuits) are made from a range of primary ingredients (wheat, rye and corn) and that if they were to look at the chemical composition of each shape, they would get a very different set of trees. The students normally make the link to DNA. For 15- to 16-year olds, it is sufficient to say that some species have similar DNA even though they look different. For older students (16+), convergent and divergent evolution can be discussed in more detail.

An extension activity for older students could be a discussion of the difficulties associated with extracting uncontaminated DNA from ancient samples (see, for example, Hayes, 2011).

A further extension activity could be to introduce the molecular phylogeny activity described in Kozlowski (2010).

Acknowledgement

The activity using metal objects was originally developed by the Open University's Science Course






Images courtesy of Isabelle Kling

Foundation Course Team for the S100 Course, Unit 21 'Unity and diversity', Study Guide. This version has been adapted from Barker (1984).

References

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Hayes E (2011) An archaeologist of the genome: Svante Pääbo. *Science in School* **20**: 6-12. www.scienceinschool.org/2011/issue20/paabo

Kozlowski C (2010) Bioinformatics with pen and paper: building a phylogenetic tree. *Science in School* **17**: 28-33. www.scienceinschool.org/2010/issue17/bioinformatics

Web reference

w1 – Download pictures of the metal objects to use for the activity from the *Science in School* website. www.scienceinschool.org/2013/issue27/phylogenetics#resources

Resources

Tafforeau P (2007) Synchrotron light illuminates the orang-utan's obscure origins. *Science in School* **5**: 24-27. www.scienceinschool.org/2007/issue5/orangutan

The website of the Natural History Museum in London, UK, offers excellent information about evolution. See: www.nhm.ac.uk/nature-online/evolution

If you found this article useful, why not browse the other teaching activities in *Science in School*? See: www.scienceinschool.org/teaching

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John Barker taught at a school in London, UK, for a decade and then moved into science teacher education, first at Borough Road College, London, and then at the Centre for Science Education, Chelsea College, London, during which time he was one of the team that produced Nuffield Advanced Biology. He is keenly interested in initial science teacher education courses and was director of the course at Chelsea College and, after their amalgamation, at King's College London, for more than ten years. He is now retired.

To learn how to use this code, see page 53.