← Before and After →

Synopsis

Students are asked to identify something, A, that changes into something else, B. They are asked to make a model of B (preferably three-dimensional), and make a presentation including information about the *causes* and *mechanisms* of this change. This can be in a biological context, an art context, or a technological context. Origami is used as an illustrative analog of *morphogenesis* ("form creation").

Objectives

This exercise teaches students how to use models as a way to organize, simplify, and present ideas relating to complex processes. The use of such models occurs frequently in science; the *NSES Content Strand A (Science as Inquiry)* objectives for levels 5-8 include, "Develop descriptions, explanations, predictions, and models using evidence." Depending on the context(s) chosen for investigation, any number of additional learning objectives in the life, physical, or earth sciences can also be met using this exercise.

Introduction

Think of an item that changes over time from A at time 1 to B at a later time 2:

A → B

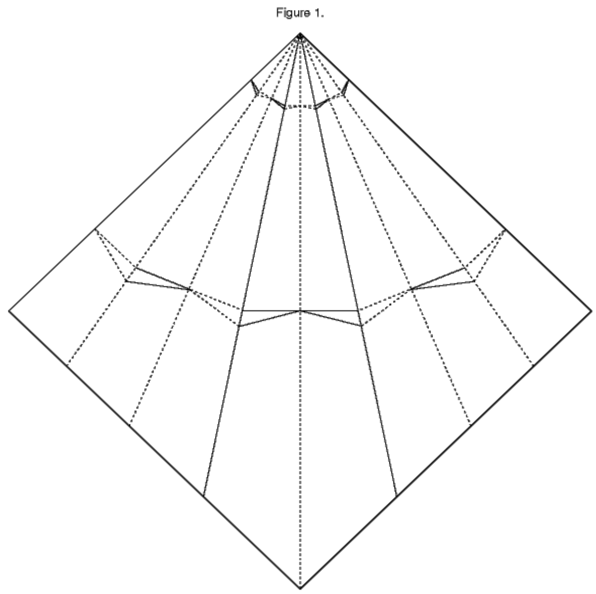
The arrow → represents change. The change has a *cause* and a *mechanism*. The cause is the *situation* that makes the change happen, and the mechanism is the *means* by which it happens. For example, a tack in the road is the cause of a tire going flat and the mechanism is air escaping through the tack hole.

Students are asked to make some product, B. In so doing, they are asked to confront and try to identify and describe these causes and mechanisms. If they take the recommended three-dimensional structural path, students learn that the making of each thing takes time in planning, acquiring materials, construction (cutting and joining), and finishing (trimming, painting), and that while all this is happening, their ideas are changing about what they are doing: by what processes they change a pile of materials into a structure.

Developmental biology is a natural subject for this exercise. One illustrative word that is used to describe the development from the egg to the chick is *morphogenesis*, Latin for "form-creation". An egg is a huge single cell with a load of yolk, while a chick is a multicellular item with many different organs and a behavior that allows it to escape from the eggshell and breathe air. Lots of 'morph' or form has been generated during this period of development.

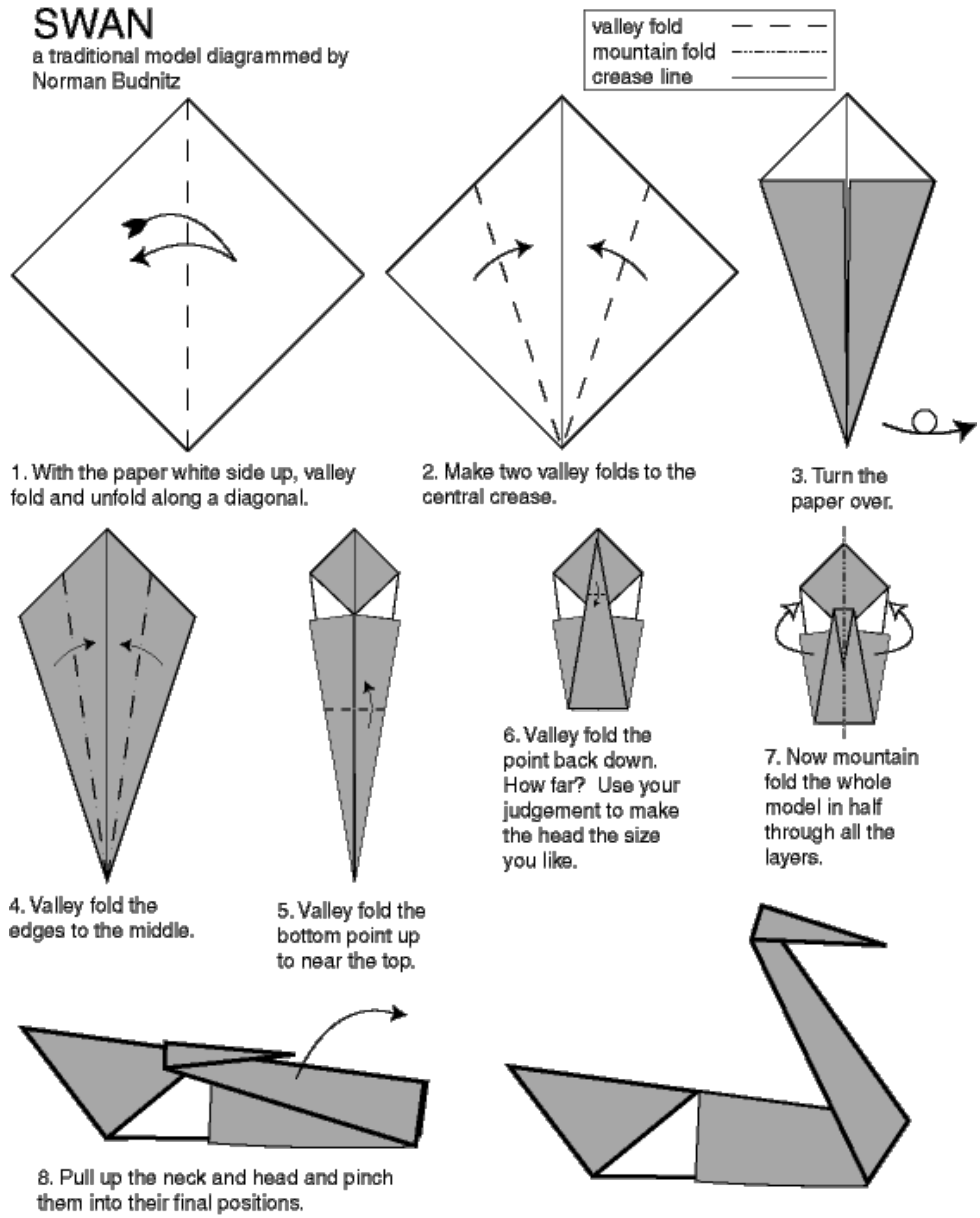
Morphogenesis is the process by which one gets from gene to protein to extracellular structure to embryo. In a playful and illustrative example, a flat square of paper can become a swan via the process of origami. Figure 1 shows the origami *crease pattern* for making a swan. In this diagram, dotted lines are *valley folds* (the crease forms a valley when seen from this side of the paper), and solid lines are *mountain folds*. Students can cut out the square and then try to fold the swan just knowing this much information. Give them five to ten minutes to try this, but since it is very difficult to accomplish, do not let them get frustrated.

Figure 1.



After the students have struggled a bit with the crease pattern, hand out squares of paper and lead them through the process as described in Figure 2. (Eight-and-a-half inch squares cut from copy paper work just fine, or you can supply 10-inch origami paper that you can buy in most any hobby store.) When they are finished and have exclaimed over the beauty of their swans, have them unfold their models and compare the crease pattern to Figure 1.

Figure 2.



The pattern of folds is the *developmental program* of the origami swan. All the necessary folds are shown, including which fold toward you and which fold away from you. But you also need to know the order in which they must happen. The developmental program of a real swan is somehow contained in the genes. It is fair to say that we do not know the complete developmental program for any organism. The Human Genome Project, a multi-million dollar effort to determine the complete sequence of genes on human chromosomes, will ultimately tell us just that--the sequence of base pairs in our DNA. However, our understanding of how that sequence translates to become human beings with brown hair, five toes, and shyness is still a very long way off. But we are pleased with any help we can get in trying to understand the complex processes.

The genotype to phenotype example can show where our present knowledge helps us and where it fails us.

If A is a gene and B is its protein product, what process or processes take place to get from A to B? You can find much of the answer in textbooks and even more refinements in scientific journals, but you will always discover that there are gaps in our knowledge: we know how genes produce the protein collagen, but we don't know how genes cause collagen to be ordered into the crossed-helical array of collagen fibers that make up the body wall of sea anemones, worms, and fishes. As in our origami example, it is one thing to know the basic information and yet another to understand the higher order processes.

The notion that all our body parts are being continuously replaced, one atom at a time, allows us to appreciate Laurence Picken's (1960) statement: " . . . at the molecular level function is changing structure and the seemingly 'static' organism is revealed as a process." Think about the chick changing into a hen. At any moment that you see it, you cannot see it growing or making feathers instead of down or learning to cluck instead of cheep. There are many processes going on at every moment of our lives, turning us from young As into older Bs.

Procedure

A $\rightarrow$ B. Students are asked to make some product, B. Optionally, they may also make A. (Categories or restrictions for B are to be determined by the teacher. Many suggestions are given below in the **Examples** section.) Students may use any media for their construction, though we strongly recommend that the product be three-dimensional.

A day or two before they begin construction, students must first turn in a *prospectus*, a written description of what they have in mind and how they propose to do it and with which materials. This gives the teacher the chance to check out the suitability of the project and to make appropriate comments.

On the due date (to be determined by the nature of the particular assignment), students must turn in their product, B, and a short (one page) written statement that will include:

- The title of the project.
- The name and/or description and picture of item A.
- The name and/or description and picture of item B.
- The *cause* of the change.
- The *mechanism* of the change.

Students will also tell their classmates about their project in a short presentation (five minutes). They should *not* read their written statements. This should be an informal presentation of what they have done.

Examples

The variations on the theme A $\rightarrow$ B are limited only by your imagination. Here are just a few suggestions:

- An introduction to developmental biology: A and B can be any 2 "stages" in the life cycle of any plant or animal. A can be a fertilized egg or zygote, a seedling, a newborn, or a hatchling, and B can be an adult or even an organism which has died.
- A comparison between biology and engineering: In an interdisciplinary course one can compare a biological example with an engineering one (what are the steps in the development/fabrication of a

bicycle or a hair-dryer?), or an architectural one (could students make a teepee from scratch?). Even theories have conceptions, development, births and deaths, and so do societies, football games, governments, and hurricanes.

- The exercise can begin with A and B being ideas and all work is done in prose, poetry or song. A sample exercise could be done this way in class to introduce the whole notion of the "Make B" exercise.
- A and B can be numbers, words, one-dimensional lines, two-dimensional pictures or, best of all, three-dimensional structures. A might be something found in nature or a junk pile, and B might be an imagined, realistic or apocryphal thing.
- Realism allows a scientific approach. A rock may become a pile of sand. In another situation, a pile of sand can become a rock. Another rock may have a fragment of it set in a gold ring. Yet another may end up with other rocks in a wall or a cathedral. A mass of microscopic rocks (clay) may end up as a pot.
- A history class could ask how one situation became another over 100 years. Economic and social structures change. There is opportunity here for teamwork, each student taking a different cause or mechanism.
- Artists turn pigment into portraits and stone into sculptures.
- Human made things are often not so useful in their second life: A car tire can become a swing. Plastic milk jugs can be combined to make a raft. What happens to an old car? An old piano? Do all swords become plowshares?
- *Orb Spider Web*. Ask students to study one. How many kinds of threads are there? Is the circular net a series of hoops or is it one long spiral? Touch a spiral thread with a blade of grass: it's sticky. Are the radial threads sticky? The spider can get caught in her own web because the spiral sticks to her as well as it does to prey items. How then does she weave this part of the web?
- *Growth Increments*. This is an endless source of material for this type exercise.
- *Turtle Shell*. The patterns of growth on the inside bony part are totally different from the growth patterns on the outside cuticular part. Guess the growth modes. Where are the cells that cause growth in each?
- *Wasp Nest*. Look carefully, using a magnifying class or a dissecting microscope if it is available. How is this made? What is paper anyway? How do we make paper? You can make paper from a sludge of fibers you get from soaking newspaper long enough. But given paper sludge, how would YOU make a wasp nest with all cells the same size and so conveniently hexagonal. Bees, too.
- *Hen's Egg With Chick Inside*. How does the sperm get into a bird's egg?

Extensions

The appreciation to be encouraged here is of the zillions of processes by which things change. This allows for lots of discussion based on things students know already, and, of course, it allows for any amount of reading to be done in associated assignments.

Discuss causes and mechanisms of change. Water erodes continents. Fire turns forests into charcoal. Pride turns Sam into a stuffed shirt. A brass tube turns breath into a trumpet solo. A squirt of adrenaline turns us from calm to torrid. War turns cars into bombs.

One year students were asked to make two masks, A and B. The result was a thrilling set of realizations about who we are, who we can become, how we are seen by others, how we get to be that way, and so on. One student made an A mask of herself as she entered college--a self-centered person who got straight As and was known and admired by her whole high school. Her B mask was her view of herself the semester she was graduating from college--no longer bragging about her superiority and expressing much more understanding about the complexities of real life and her dependence on other people. Her oral report was a short list of experiences that caused some of these changes.

The procedure outlined above has students make B and talk about A and the intermediary changes represented by the arrow ➔. This exercise can be modified in various ways:

- Students could be given A and the various mechanisms that constitute the arrow ➔. Their task is to predict and/or make B.
- Students, working in pairs, could provide A and ➔ for their partners and then have to make each other's B.
- Students could be given A and B and be asked to speculate on the changes implied by the arrow ➔.

See **What's the Rule?** for a similar exercise in the form of a math game.

Revised: February 12, 2001