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Setting the stage: developmental biology in pre-college classrooms

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ABSTRACT Exercises that employ dynamic living material have proved highly successful at generating interest in science among young students. Developing embryos and larvae are especially well suited for such endeavors, for they can be handled without expensive or elaborate equipment, and their changing nature engages students. Using amphibian embryos, which are relatively large and exhibit profound, easily observed morphological changes, and amphibian larvae, which are easily kept and observed, captures the attention of children. By designing inquiry-based exercises and focused discussion sessions, a high intellectual content can be integrated into these endeavors. The long-term implications for generating an informed citizenry, improving the participation of women in science, and empowering elementary school teachers are profound. Professional developmental biology researchers should feel encouraged to participate in these types of activities.

KEY WORDS: *lesson, education, inquiry, elementary school, classroom, axolotl, regeneration*

Background Information

Scholarly Interests of the Authors

Sandi Borland is the Outreach Coordinator for the IU Axolotl Colony. In her tenure there, she has developed an extensive outreach program to the national pre-college educational community. She has developed materials for students and teachers who want to use the Mexican Axolotl (*Ambystoma mexicanum*) in their science programs. She has worked in the schools and at the Axolotl Colony with thousands of children, in addition to giving workshops for Indiana teachers to learn how to use axolotls in science and cross-curricular activities, especially using the inquiry method to allow students to get the most out of science.

Karen Crawford is a professor of biology, with research interests in amphibian appendage regeneration. She has transferred some of her interests in science to the children in her own family and to young school children in a local school. Her goal is to generate intellectually stimulating experiences that require minimal expenditures of time, energy, and monetary expense. She has devised limb regeneration exercises that have proven to be highly effective for both the students and their teachers. An example of her research interests can be found in the following:

CRAWFORD, K., (2001). Ooplasm segregation in the squid embryo, *Loligo pealeii. Biol. Bull.* 201(2): 251-252.

CRAWFORD, K., (2002). Culture method for *in vitro* fertilization to hatching of the squid, *Loligo pealeii. Biol. Bull.* 203(2): 216-217.

Victoria Brand is a collaborative peer teacher in science for 11- to 14-year-old students. Initial experience with outreach efforts produced enough enthusiasm and ideas among the teachers and students at her school to inspire follow-up projects in subsequent years, and she and her fellow teachers have developed a whole curriculum unit from the initial project.

Changes in Shape, Size and Color capture the Imagination of Young Students

Introducing young children to the life sciences through study of developmental biology (though not often called *developmental biology* in pre-college situations) is a relatively common strategy. In the United States, students study biological life cycles as part of the science standards set by national- and state-level school administrative committees. Cocoons are brought into the classroom for students to watch the emergence of a butterfly or moth. Mice, hamsters, and gerbils are housed as pets, and rodent pups are reared (even if unintentionally) as class projects. Young children watch such events and are fascinated as they observe changes. Then they ask questions. The use of living material thereby serves as a jumping-

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off point for scientific inquiry. A natural interest in changing shapes, sizes, and colors leads young students to ask questions based on their observations and to offer predictions based on their prior experiences. This process in turn leads to a search for answers, which are obtained by asking a teacher or expert, doing an Internet search, or reading available literature. This scenario usually occurs on its own, regardless of whether it is part of a formal lesson. Studying developmental biology is integral in the natural study of living things. It is a study of beginnings, of change, and of structure, process, and purpose. Little wonder that it captivates the intellectual energy of students.

Use of Living Material in the Public School Classroom is often the most Cost-Effective Strategy for generating Interest in the Biological Sciences

The U.S. National Research Council (an advisory board to the U.S. government) has emphasized that:

> *Biological science that is presented to elementary school children should have natural history as a major focus, be integrated with other subjects wherever possible, and emphasize observation, interpretation, and hands-on involvement, rather than memorization of facts... Students... should observe and care for organisms in the classroom* (National Research Council, Committee on High School Biology Education. [1990]. Fulfilling the promise: Biology Education in the Nation's Schools. National Academy Press, Washington, D.C.).

Live material with accompanying supplies can be obtained from various biological supply companies (e.g., NASCO Scientific, Ward's Biological Supply, Carolina Biological). Many materials can be obtained locally or even collected from nature (at no cost). Supporting materials and activities for classrooms can usually be found on the Internet. The teacher doesn't have to take a course to teach with these materials. They can choose to learn with their students, demonstrating by their own curiosity and questioning the love of inquiry and discovery. In the United States, the usual teacher-training programs for elementary school teachers emphasize language and math teaching skills, at the expense of science skills. Teachers who elect to use living material in the classroom find themselves empowered, and easily able to compensate for lack of formal science training by engaging and joining students in relatively straightforward yet intellectually stimulating exercises. In a study of 86 ten-year-old students, it was observed that using small, live animals increased interest in and motivation for studying biology (Tamir and Schurr, 1997).

Fig. 1. A five year-old child, observing the living axolotl embryo at the IU Axolotl Colony. *Photo courtesy of Sue Hicks and Jitka Horne, Hoosier Courts Cooperative Nursery School.*

Using living material in the early classroom has a subtle, yet predicted influence on career choice among young girls (Fig. 1). Girls are thought to make important career decisions in the late elementary school years (ages 9-12) (Orenstein, 1994). Elementary school teachers in the United States are overwhelmingly female and provide role models for young girls. These teachers, therefore, need to be enthusiastic and involved in their science teaching. When teachers are engaged, students tend to follow suit. Girls are thought to develop more confidence in their science abilities when they are engaged in hands-on exercises that spark their curiosity and give them an embodied experience (Rosser, 1997). In this manner, a long-term beneficial effect on closing the gender gap in science is likely to result.

Information-Age Opportunities are increasingly Available to Young Students

In today's world, the Internet has greatly enhanced the access children have to resources at all levels of complexity. A student in elementary school can learn about pigment mutations in amphibia by using a search engine, or, log onto one of the many attractive science sites designed especially for young students. Students aged 13-18 can research a genetic disease and become acquainted with ideas and jargon concerning its causative basis.

In addition, as a result of increased outreach efforts of U.S. colleges and universities, materials and personal expertise are now available to some of our pre-college classrooms. In many instances, teachers and students can learn science directly from practicing scientists. During such collaborations, students learn about authentic research projects while developing an understanding and respect for the power of the scientific method. *Research* itself can become part of the lesson and is then viewed as a practical, accessible, and necessary part of their world.

Three Examples of Projects that introduce Young Children to Developmental Biology

Three successful outreach programs are described below that illustrate the profound effect college/university outreach programs can have on the learning experiences of young children. These descriptions are designed to encourage professional developmental biology researchers to get involved with public school science classes. The motivating effect researchers can have on both young students and their teachers is very powerful.

The first two descriptions explain on-going outreach programs for pre-school through elementary school age children, while the third description explains an on-going middle-school project.

Fig. 2. (Left) Pre-School teacher, Jitka Horne, learns about developing axolotl embryos with her students. *Photo courtesy of Sue Hicks and Jitka Horne, Hoosier Courts Cooperative Nursery School.*

Fig. 3. (Right) Using living material as a focus is early education classrooms has wide appeal for more than basic science. *Children discuss, draw, collaborate, observe, predict and discover as they get experience in basic biology. Photo courtesy of Sue Hicks and Jitka Horne, Hoosier Courts Cooperative Nursery School.*

What am I going to do with All These Axolotls? *by Sandra Borland*

For more than 15 years, the Indiana University Axolotl Colony has developed collaborations with many schools and teachers, from preschool through pre-college levels. The positive effects of this program have been noted and even documented over the years by many teachers and administrators and their students. For example, Ginny Coppedge, a local teacher of 7-8 year olds, has explained the manner in which students who were indifferent to school and learning became enthusiastic not only about science but also about writing and drawing as well (Coppedge, 1996). Similar stories have been heard from public school science teachers using axolotls in their classrooms at all levels. Those teachers were eager for something different to stimulate interest in students, who often complain of being bored in the classroom. Often these teachers are also trying to find an interest in and method for teaching science themselves.

In the United States, pre-school and early grades are often ignored with regard to learning science. Our culture emphasizes math and language development at early ages, often at the exclusion of science. Even now, with new education guidelines that require science be taught at the early grade levels, science is punched and prodded into curricula that will still place greatest stress on math and language. Unfortunately, this does not cultivate the natural interest of young students in the world around them. Their world is real, not abstract, like math studies and reading sometimes appear to be. The ideal is to use science to bring math and reading into the real world. Let the natural interests of the students drive their desire to know how to read and mathematically analyze. This is what many teachers in early grades have done with our axolotls.

In the course of the I.U. Axolotl Colony's normal breeding program, which is entirely self-sustaining and supplies materials to labs all over the world, we accumulate surplus animals and embryos. Although the availability of surplus material did not stimulate the outreach, it did make it easy to participate in outreach activities. We had animals to spare and teachers who wanted something different for their classrooms, for their students, and for themselves. Consequently, axolotl aquaria have now been set up in classrooms in many schools around the United States.

Initially, we brought children into the colony for tours (Fig. 1). We set up axolotl life-cycle demonstrations and collected representatives of other amphibian and reptilian species. We prepared booklets with collections of axolotl art and information for students to take home and share with their families. We discussed the axolotl's status as an endangered species and issues of conservation and the environment. We reviewed anatomical structures and purpose: What make axolotls special? How do they grow and change? What makes axolotls different from other amphibians and from reptiles, mammals, birds and fish? And we answered questions, endless questions! Anyone who has worked with young children knows that keeping them engaged and interested in the same topic for 30 minutes is extraordinarily difficult. Nevertheless, axolotls succeeded in holding the attention of even the youngest students. I found that if I let the students' questions drive the discussion, we could hold their attention for longer than 30 minutes. Students are so interested that they would even listen to each other's questions! Teachers very often ended up thrilling their students by adopting an axolotl or two for their classrooms. A year later we sometimes received messages and questions concerning the now adult-size adoptees, now loved by the next year's crop of students. Very often we received panicked yet excited calls and e-mails from teachers whose now grown axolotls had just produced several hundred eggs. They were amazed, their students were thrilled, and the event often created excitement throughout the school and the community. Many teachers

Fig. 4. Graphic representations by preschoolers tell us much about their abilities to observe and relate to their world. *Here, not only do we see surprisingly accurate drawings of developing axolotl embryos, but you see that the child is involved with that world as part of her own. Sketch courtesy of Sue Hicks and Jitka Horne, Hoosier Courts Cooperative Nursery School.*

and their classrooms have been reported in their local newspapers. Other teachers from the schools or the region would contact those teachers or the colony so that they could do the same thing in their own classrooms. Such is the effect of natural science, and, in this case, of axolotls, on stimulating interest in students, their families, and teachers.

Eventually, we began to travel with our axolotl material to classrooms and school community science fairs. Time after time, I found that if I let the students guide the discussion through questions and comments, the seriousness and involvement of each individual student increased. They observed and asked questions. I answered their questions and listened to many of their stories.

More and more teachers have discovered the joy of teaching with axolotls. Below is a list of some of the activities that can be done with young students (Figs. 2, 3):

Early Axolotl Embryos

Count embryos
Manipulate and divide embryos into sets
Sort embryos by stage of development
Prepare staging series (which comes first, second, third, etc.)
Observe effects of gravity
Experiment with effects of temperature on developmental rate; collect data from test groups and represent differences graphically
Use simple dissecting scope or magnifying glass to observe embryo structures and changes
Observe beating heart and blood moving through the 3 chambers
Observe circulation in gills of near-hatchlings
Draw pictures of observations or changes in a lab notebook

Axolotl Larvae

Observe development of limbs
Experiment with the effects of temperature, type and quantity of food, and other parameters on growth rate
Study habitats (natural and artificial)
Experiment with environment preferences
Collect data on growth rates
Compare axolotls with different pigments
Observe locomotion
Compare with other species and animal groups
Discuss metamorphosis and "growing up"
Discuss ability to grow new parts and interest of scientists in this process
Map natural location of axolotl on world map
Observe pollution in local streams and relate to axolotl habitat
Read about axolotls in culture and history
Create myths/stories about axolotl creation

Today, we have axolotl developmental biology kits available for teachers to purchase at a nominal cost. The idea behind the kits was to make it easy for teachers to have as large or as small an axolotl project as they can handle, with the supplies and information at hand to get them started. Kits can be ordered with embryos or larvae and come with basic supplies (i.e., water treatment chemicals, food) and information on development and care and safety for students and animals.

The inquiry model is ideal for exploring the developmental biology of axolotls. Thus it is important not to serve up too much information but instead to allow students to think and ask and discover for themselves. Their observations are often astounding, and they sometimes notice significant details that teachers often miss. For instance, when some students try to portray axolotls by drawing, anatomical structures are sometimes included that adults

Fig. 5. Researcher Karen Crawford discusses axolotl regeneration with elementary students.

never notice. Also, artwork reveals concepts of relationships, parenting, nature, structure and purpose (Fig. 4). Drawing axolotls has helped teachers learn about their students, not just about axolotls!

When teaching science, it is important not to underestimate the information young students are ready to process and understand. Correlations and comparisons are how children learn from the very beginning of life. This should continue throughout development and should be the guiding principal helping children understand the interrelatedness of the species and the environment, a complex yet logical process for a child.

Elementary Students study Regeneration with a Researcher *by Karen Crawford*

Over a period of one month, 20 students in a Montessori (private elementary school) combined classroom for 6–9 year olds observed normal hand regeneration on an adult axolotl. Montessori schools are privately operated around the world and emphasize, among other principles, the notion that children learn best from engagement, and that cooperation (vs. competition) between students fosters student learning. Thus, this experimental exercise was well received by students, teachers, and parents.

The first day, while the animal was being anesthetized, we discussed using anesthetic, regeneration in amphibians and other animals (Fig. 6), general laboratory safety, feeding and animal care, and making regular observations (Fig. 5). Since they had previously drawn the phases of the moon over a month's time in the fall, I distributed a calendar to each student for them to draw the phases of regeneration. Once the animal was anesthetized, it was passed around in its container for the students to observe. Next, it was placed on a plate and its right front hand was amputated using small scissors. Upon returning the animal to its water, the students observed it as it "woke up." The axolotl remained in the classroom for one month. Students took turns caring for it, drew pictures of the regeneration process, and compared their pictures with illustrations I provided. At 2 weeks, I returned to the classroom to check on how things were going and to answer questions. At that time, the limb blastema was at the late bud stage. By one month, four digits had formed. The students kept the animal until each of them had had a chance to care for it. At 6 weeks, I met with the class again to review their data and the outcome of our experiment. Benefits? Their observations and questions were amazing! The students and parents now seek me out to tell me extraordinary things. Science came alive in this classroom. Rather than dealing with an abstract phenomenon, this exercise had a profound and personal meaning for each and every student. The procedures we employed were as follows:

Day 1 (~ 1.5 hours duration)

1. Introduce the animal, describe where it lives and why it is unique. Answer questions.
2. Discuss anesthetic and why we use it. Allow the students to tell their stories about receiving anesthetic. Place the axolotl (~8 cm in length) in 0.007% benzocaine in 20% Holtfreter's solution. While discussing regeneration, amputation, and animal care, pass the container with the animal in it around for the students to observe.
3. Introduce the idea of regeneration and metamorphosis. This stimulates stories of lizards losing tails, crabs without claws, starfish without arms, even uncles growing fingertips back. Encourage students to share their stories with the entire class.
4. Describe the amputation procedure, showing students the scissors that will be used. Answer questions about blood, and assure everyone that there will be very little shed.
5. Once the animal is "asleep" (~ 10 minutes), amputate one hand. Show each student the animal's amputated hand.
6. Return the axolotl to 10% Holtfreter's solution, answer questions, and wait for the students to notice the animal has awakened.
7. Review animal care, feeding, cleaning, and how to make observations.

Follow-up 1 and 2 (~45 minutes each)

1. After 2 weeks, I returned to the classroom to check on how things were going, answer questions and show the class some other axolotls (representing different pigmentation mutants). The amputated axolotl, now named "Nippy," was doing well and had a nice late bud blastema.
2. After a month, Nippy had developed four digits and was growing well. The students decided to keep Nippy until everyone had a chance to feed, clean, and record regeneration for the class.

Conclusions

1. Regeneration to the digit stage was complete in 4 weeks.
2. The students learned a lot about regeneration, scientific observations, and animal care.

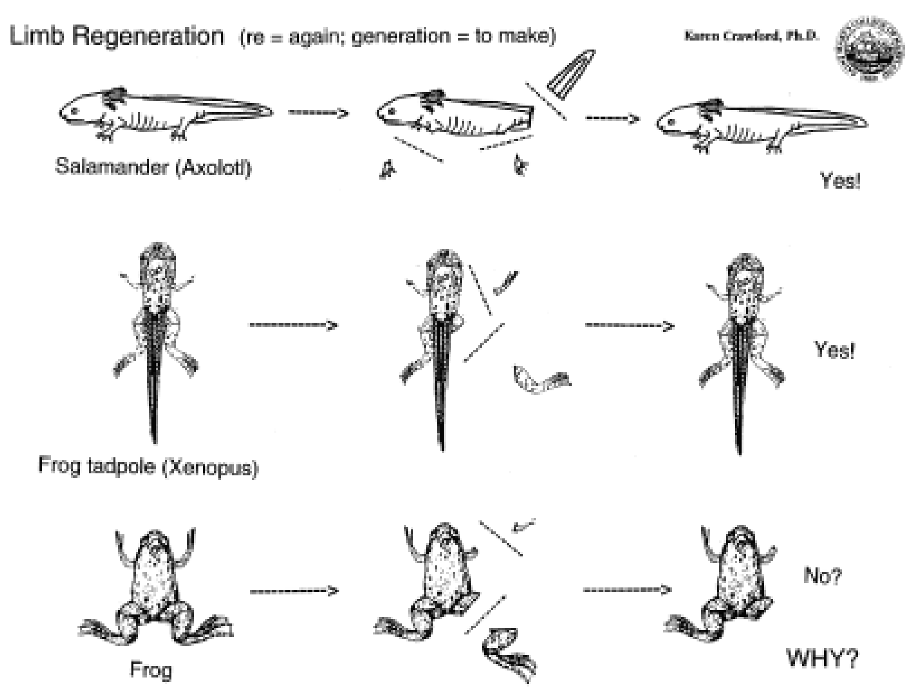

Fig. 6. Handout used with elementary students comparing regeneration in different amphibians at different stages in the life cycle.

Fig. 7. Middle-school students (aged 12-15) weigh and measure juvenile axolotls as part of a science lessons studying metamorphosis in amphibians.

3. A favorable memory was achieved. I am frequently approached by students throughout the school, who talk to me about their thoughts and observations about science, especially the girls!
4. When possible, follow-up visits enhance learning and future connections with students.
5. First, second, and third graders are an enthusiastic and willing bunch of scientists!

The Juvenile Salamander in the Middle - School Classroom *by Victoria Brand*

What do you get when you cross 200 juvenile salamanders (*A. tigrinum*) with 200 excited inner city 12-13 year olds? Well, if you add to the mixture two dedicated teachers, 50 ten-gallon tanks with assorted humming water pumps, shipments of worms, and a definite "what is that smell?" you end up with the Osborn Middle School "Water Dog Unit." Over the past 3 years, students have learned about "real science" by doing a variety of exercises with our axolotls.

Getting our Program started - an Unlikely Beginning

Four years ago, a senior biology undergraduate at Arizona State University (Tempe) wrote a grant proposal that was intended to support the salamander brain research being conducted at the university by creating a source for salamanders. The idea of the proposal was to find a middle or secondary school willing to raise juvenile salamanders to maturity and then send them along to the university's research laboratories. When our science collaborative peer teacher heard of the project, she recognized it as a golden opportunity for our middle-school students to conduct scientific research. Additional grants were written and eventually funded by the U.S. National Science Foundation and PetSmart (a retail store which specializes in pet supplies). The university grant paid for the first batch of youngsters. The seventh grade science teachers developed an instructional unit which would support the State of Arizona standards for teaching science and which would also accomplish the university's goal of being supplied with large numbers of metamorphosed salamanders.

Problem Solving as a Student Endeavor

How to get large numbers of juveniles to metamorphose? That became the scientific question for the class. It was up to the students to develop hypotheses and conduct appropriate research. What wonderful ideas 12 and 13 year olds can devise! The first year our animals had a massive fungal infection. Students used their computers to e-mail the university, called on a local exotic animal veterinarian, and surfed the Internet to research information to help them combat that plague. We now have a gallon of Rid Ick (antifungal medicine) available at all times. Another teacher developed a wonderful lesson on fungus to go with the unit on salamander growth. Over the years, both teachers have infused technology throughout the lessons. One teacher developed a lesson to measure the amount of oxygen elodia infuses into water. While we have never become the salamander factory intended (the students have not quite discovered the key to the puzzle), the relationship between Osborn Middle School and the University of Arizona has grown, and the project lives on, impacting the lives of hundreds of seventh graders every year.

A Typical Day in Aquarium Central

A classroom day usually begins with several students arriving before classes begin to check on their "dogs" (as they are fondly referred to). Students can be observed feeding, cleaning, observing their subjects and discussing any changes they have discovered (Fig. 7). When the bell rings to begin class, students are given instructions at the beginning of the 90-minute period. Lessons ranged from computer research of the characteristics of the salamander and its habitat, to a math lesson where students calculate the cost of the entire operation. The remaining part of each day involves the students carefully removing their animals from their tanks and taking measurements in both grams and centimeters that are carefully entered into tables the students have prepared in their lab books. Visual observations are recorded to see if there are notable changes in tail length, gill length, legs, or coloring. Students examine their animals to determine whether the experimental variable they have applied has caused the process of metamorphosis to commence.

While students are working on their projects, teachers walk around the classroom asking questions and listening to excited students revelations. Occasionally there is an animal fatality, and the specimen is carefully placed in a plastic bag and frozen for use by our local wildlife rescue organization.

Project Outcomes

By the end of the unit, some animals will have metamorphosed while others remain as juveniles. Most are adopted and find homes with their seventh grade scientists. We have some still living after 3 years, as reported by students who return to our classroom to share their memories. The rest are returned to the local vendor.

The groups create PowerPoint presentations that illustrate the hypothesis they were testing as well as the data and the results of the experiment. They share this with each other in a mock "convention of scientists." They also create an Excel (computer) document that graphs their measurements over time to insert in their presentation. Forty of the students are selected—by application—to attend an all-day field trip to Arizona State University to share their findings with college students and professors and to have a chance to view labs and see the university's animal facilities.

The students leave our class with an increased knowledge of the scientific method, an understanding of metamorphosis, and new questions. As in real life science, sometimes the variable chosen has no effect, and that is an acceptable result. After 3 years, we have not found any consistent variables to report, but we are starting to see possible patterns. Interestingly, adding food coloring has had a rather consistent effect in a number of tanks. The students thought perhaps the threat of water contamination caused the animals to accelerate changes?

Some of the most valuable aspects of this project include the students' enhanced ability to collaborate, the sparkle that comes on in a child's eyes when the idea of a college education becomes a real goal, and how they leave our class respecting living beings in a world where life is often an expendable commodity.

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