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Lesson

The Developmental Origins of Mythology: A Pandemic-Inspired Innovative Developmental Biology Laboratory Exercise

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Abstract

From an experiential, hands-on perspective, the Developmental Biology Laboratory is easily amenable to a wide range of undergraduate-friendly experiments. Thus, pivoting to a virtual laboratory during the COVID-19 pandemic required significant reconfiguring to capture the essence of student-driven experiments. The innovative laboratory activity described here was inspired by the nuggets of truth contained within many of the mythological origin stories. Students were asked to propose a logical developmental process that could lead to a specific mythological creature. In this article, the mythology-based developmental biology activity is described, including its inspiration, instructions and support for the students, and sample work.

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Learning Goals

Students will:

◊ understand the major steps of embryonic development.

◊ recognize how development occurs across animal species.

◊ appreciate how chimeric organisms are generated.

This lesson aligns with the following society-generated learning goals:

◊ From Developmental Biology Learning Framework:

» How is the basic body plan formed?

» How does loss of totipotency and pluripotency lead to progressive specification in cells?

» What roles do cell determination and cell specification play in organogenesis?

» How are the axes formed?

Learning Objectives

Students will be able to:

◊ identify typical axis formation, gastrulation, neurulation, and limb bud formation.

◊ evaluate an experimental result to determine whether axis formation and patterning occurs typically.

◊ identify neural crest and epicardial placode derivatives.

◊ evaluate a chimera to determine the developmental stages used to generate specific chimeras.

◊ concisely describe an example of atypical development.

INTRODUCTION

From an experiential, hands-on perspective, the Developmental Biology Laboratory is easily amenable to a wide range of undergraduate-friendly experiments. Some of the traditional model organisms, such as *Drosophila*, were studied explicitly because of their ease of use in the undergraduate setting (1). Similarly, this author had designed the in-person Developmental Biology Laboratory experience to include learning basic techniques in developmental biology, developing general science skills such as keeping a useful lab notebook, and designing and carrying out experiments using the chick (*Gallus gallus*) model organism. In particular, the emphasis on experimental design, performance, and assessment has benefits ranging from better comprehension of learning objectives to improved preparation for future careers to reducing barriers for research in other settings (2, 3).

Given the hands-on design of this laboratory, pivoting to a virtual laboratory during the COVID-19 pandemic proved to be challenging (4). When designing the virtual laboratory, the author reflected on what activities could capture the essence of the in-person experience and attempt to meet the same learning objectives. In-person, the overall course learning objectives include (i) becoming competent at basic developmental biology techniques; (ii) describing typical chick development; (iii) designing, performing, and evaluating experiments to disrupt typical chick development; and (iv) predicting developmental outcomes based on a generated or given set of data. Working virtually, students would not be improving their bench skills this semester, and so the first learning objective was replaced with developing their data analysis skills. Virtual activities could help students learn typical chick development and evaluate published data sets (learning objectives 2–4), but a key aspect of the course—student-driven experiments—was missing. These in-person, student-designed experiments would have allowed

students to disrupt developmental processes such as axis formation, gastrulation, neurulation, and limb bud development.

Because creating personal chick-based research kits for 19 students was not realistic, the author needed an activity that would challenge students to compare an atypical organism with the typical developmental patterns. The author specifically wanted a hands-on model to engage students in the deeper learning that occurs when they have a model to interact with (5). Many mythological creature origin stories represent an attempt to describe a novel experience based on the current knowledge at the time. For example, centaurs were likely imagined when the ancient Greeks first encountered horseback nomads (6), and manatees are the likely inspiration for how many sailors claimed to have spotted mermaids (7). Inspired by the nuggets of truth contained within many of the mythological origin stories, in this laboratory activity, students were asked to propose a logical developmental process that could lead to a specific mythological creature. The selected creatures demonstrated disruptions in the same developmental processes that students would have explored in-person. Thus, to describe the potential origins of their mythological creatures, students had to successfully demonstrate their understanding of what tissues were generated during gastrulation, how axes are formed, what signaling pathways contribute to the basic body plan, and when cells become more restricted regarding their ability to differentiate. Based on this knowledge, students could then test their comprehension of the typical developmental patterns by exploring what could change during development to lead to a mythological creature.

Intended Audience

This Lesson was utilized for advanced biology undergraduate students at a liberal arts college.

Required Learning Time

This Lesson requires approximately 10 minutes to introduce at the beginning of the semester, a few minutes to check in with students each week during lab, and one lab period for presentations at the end of the semester. If an instructor is going to utilize many mythological chimeras, spending one lab period exploring how chimeras are generated is recommended. (See Table 1 for a suggested timeline.)

Prerequisite Student Knowledge

Before completing this Lesson, students should have completed most of a one-semester Developmental Biology Laboratory. Based on the specific creatures listed in Table 2, students should have gained background knowledge in major topics including gastrulation, neurulation, axis formation, limb formation, and generation of chimeras prior to completion of this Lesson.

Prerequisite Teacher Knowledge

The instructor should have a basic knowledge of major topics in Developmental Biology, particularly those topics listed for the students. Useful resources include Barresi and Gilbert's Developmental Biology, 12th edition, and Wolpert's Principles of Development, 6th edition. Additionally, the instructor should only choose mythological creatures for which they can come up with at least one plausible hypothesis.

SCIENTIFIC TEACHING THEMES

Active Learning

Throughout this author's Developmental Biology Laboratory, students work in self-selected pairs. Thus, even though these mythological creatures in this Lesson are individual assignments, students engage in group discussion, working in pairs to practice describing their creatures and relating their creature's development to the week's content. Discussing observations with their partner also gives students an early opportunity for feedback. Throughout the semester, students are tasked with reviewing their mythological creature each week and recording their observations (*i.e.,* did the developmental process that the lab focused on occur typically in their creature?) in their lab notebooks.

At the end of the semester, students give short presentations that summarize their mythological creature. Part of the students' assessment includes their ability to respond to peer questions, which encourages active listening during classmates' presentations. The author's student body takes this responsibility seriously, with at least two different students posing questions for each presenter. Together, these practices are expected to increase students' grasp of major concepts and improve performance on assessments (8).

Assessment

The final assessment is an oral presentation, which is evaluated based on content and presentation. The students had the option to self-evaluate their presentations by comparing their work with the shared grading rubrics (Tables 3 and 4). This author used the shared grading rubrics to ensure that students met the objectives of the Lesson when evaluating student learning.

Inclusive Teaching

This Lesson was designed to allow each student an opportunity to become an expert. Attempting to have each student evaluate a different mythological creature meant that students would not be directly comparing their results with their peers. When evaluating their mythological creatures, students could focus on those aspects of development that sparked the most interest. Finally, because terms like "deformed" are often associated with mythological creatures, the lab practiced inclusive language (9) as the students welcomed atypical development into the lab. The author framed their development as atypical, rather than abnormal or monstrous, and encouraged students to brainstorm the benefits of their creature's anatomy. Thus, this practice helps counter the implicit bias that many individuals with disabilities face (10).

LESSON PLAN

Pre-Semester Preparation

Having three-dimensional, physical models helps students engage with their course material and take ownership of their learning (5). To ensure that students had a physical specimen to study, the author generated a list of potential mythological creatures. Mythological creatures needed to have clearly discernable features, and the author needed to be able to generate a plausible developmental hypothesis to explain

how the mythological creature could form. Finally, a model of the mythological creature needed to be easily acquirable (*e.g.,* from Amazon) at a reasonable per-student cost. The mythological creatures that met these criteria are listed in Table 2. Models were ordered early enough over the summer to allow time to assemble lab kits. Because this lab was taught virtually, lab kits, including the mythological creatures, were mailed to students immediately prior to the semester.

Introduction of the Project

The mythological creatures and the lab exercise were introduced during the first week of lab: The author asked students to analyze their creatures each week to determine whether the stage of development that was being assessed had proceeded typically in their mythological creature. Students recorded any observations in their digital lab notebooks, so the author could track their progress throughout the semester. As they identified what was atypical about their mythological creature, their task was to formulate a hypothesis that would explain their creature's origin. At the end of the semester during the last week of lab, students presented a 3-minute thesis-style (11) description of their creature, a hypothesis for the creature's developmental origin, and evidence had learned throughout the semester. The students' handout (Supporting File S1) included the following set of guided questions to help students with their analysis throughout the semester, and to help prepare their presentations:

- Introduce your mythological creature. What is atypical about your creature?
- Propose your hypothesis: How did your creature arise?
  - If you have a chimera, where did its parts come from?
- Present your evidence: What labs from this semester helped to explain the developmental outcome you observed?

Additionally, the student handout included the grading rubrics (Tables 3 and 4), so expectations were clear from the beginning. Finally, the author described how to design their presentations and provided a sample presentation (Figure 1, with script provided in Supporting File S2). Students could use up to three slides (no animations, gifs, transitions, etc.) to address the three guiding questions above.

Mid-Semester Guidance

Throughout the semester, students worked with a partner to evaluate typical embryonic development. Each week in lab, they were encouraged to discuss their mythological creature with their partner and ask questions.

Many of the mythological creatures were chimeras, *i.e.,* they were formed from two or more species. Thus, one specific lab focused on how chimeras were generated in the research setting, and students were asked to spend extra time that week determining whether their creature was a chimera. If the student had received a chimera, their goals were to determine what species contributed to it, whether one species was clearly the host, what body parts would have been combined, and at what stage during development a surgery would have needed to occur to combine the species observed in the fully formed chimera.

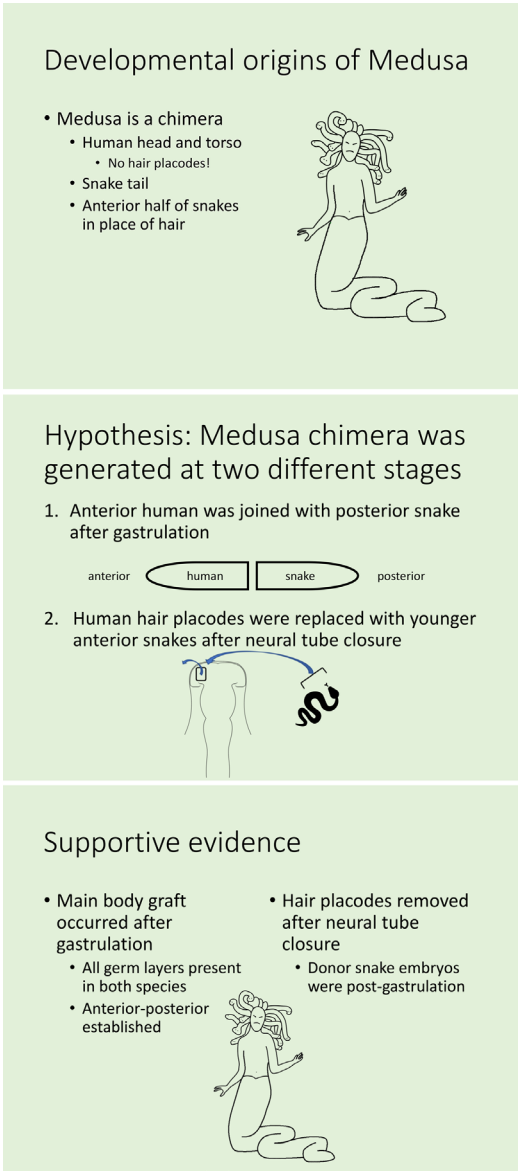

Figure 1. A sample presentation, depicting the potential developmental origins of Medusa.

To help students prepare their presentations, the instructor had informal conversations with each student to identify common presentation challenges and coach the student, such as how to navigate and implement effective transitions between slides and how to design clear slides.

Final Presentations

At the end of the semester, students communicated their results using short, focused presentations. To aid students in their preparations, they had access to the grading rubrics (Tables 3 and 4) and an example presentation (Figure 1). Half of the presentation grade was based on the presentation content: did students generate plausible and well-supported hypotheses? The other half of the presentation grade was based on presentation skills that the author wanted the students to practice (*e.g.,* transitions between slides). Grading rubrics clearly laid out the criteria for earning points. Presentations

were timed to ensure compliance with the three-minute time frame, and all students received at least one question from their peers or the author.

TEACHING DISCUSSION

In the Developmental Biology Laboratory, students are challenged to understand typical embryonic development and predict developmental outcomes in response to an experimental manipulation. Evaluating mythological creatures to predict the creature's developmental process recapitulated these major learning goals. Students had to be able to identify typical axis and limb development. For students with chimeras, they had to discern the developmental stage at which each part of the chimera was isolated and recombined. By attempting to give each student a different mythological creature, the students also benefited from learning about the potential origins of their classmates' creatures, emphasizing some of the experimental variety that the in-person laboratory encourages.

Among the 16 students in the lab, all 16 students correctly identified what was atypical during their mythological creature's development. These atypical developments included duplication of the anterior portion of the anterior-posterior axis in Cerberus, what specific regions of different embryos contributed to chimeric creatures, and disruption of the Sonic hedgehog signaling pathway in Cyclops. When proposing how chimeras were constructed, students paid close attention to whether a chimeric transplant had to be able to generate all three germ layers (*i.e.,* it would have been transplanted prior to gastrulation) or a specific tissue (*e.g.,* a hair or feather placode). Together, these hypotheses reflected the students' understanding of building the body plan overall and the potential of cells as they become more restricted. All hypotheses were plausible based on what the students had learned during the semester, testable, and falsifiable. The students successfully applied what they had learned with model organisms to support their hypotheses regarding the origins of these mythological creatures. Providing students with rubrics that laid out clear expectations ensured that the presentations were thoughtful, concise, and well-designed. The most challenging aspect for students was keeping their presentation within 15 seconds of the three-minute goal. The average grade was 29/30 possible points.

Watching the students' presentations was astounding. The students did an exceptional job assessing their mythological creatures and using what they had learned throughout the semester to generate their presentations (see Supporting File S3 for an example). They demonstrated a clear grasp of typical development, and each student had become an expert in their specific mythological creature. The notes section of the slides demonstrates how much content was included beyond the scaffolding text on the slides and even includes some of the transitions that the student used. As an instructor who has sat through countless presentations where the presenter did not quite understand or care about the material they were presenting, these three-minute presentations were the absolute highlight of the semester. The students in the (virtual) audience were engaged and asked thoughtful questions.

When asked what virtually adapted activities should be kept after the lab returned to being held in person, one student commented: "*I absolutely think she should keep the… mythological creature! It makes me feel like a kid again!*" This student's joy is palpable, and activities that can increase student engagement as we transition out of the COVID-19 pandemic will be essential for re-engaging students. In addition to the benefit of helping students re-commit to their learning, increased engagement is associated with higher grades in the biological sciences (12). This re-engagement may also encourage students of diverse backgrounds to better envision themselves as scientists, as a lack of diversity persists within the field (13).

This activity is easily adaptable. The instructor can include whatever creatures they want (*e.g.,* a Harry Potter-themed set of creatures) for their budget. The author wanted students to have a tangible object to inspect, but it would also be possible to use images instead. Because so much variation exists among how mythological creatures are represented, the author recommends giving the student a specific image or model to ensure that you and the student are on the same page. As a potential pitfall, however, limiting the pool of mythological creatures to those for which an affordable model can be found means that an instructor may have a challenging time finding a different creature for each student in the lab. For longer presentations, instructors could have students include the primary literature to support their hypotheses or describe an experimental plan to test their hypothesis. The experimental section in particular has ample room for exploration, with potential experiments ranging from gene expression analysis to gene editing. With these modifications, instructors could also opt to make the grading criteria more stringent and include class-wide discussion of what makes an effective presentation. Additionally, instructors could include a self-assessment to encourage students to reflect on their own learning experience and a peer assessment to help students develop their constructive feedback skills. Finally, this Lesson is not restricted to the laboratory and lends itself to cross-disciplinary assignments in collaboration with history or literature.

In summary, having students brainstorm the developmental origins of a mythological creature is a low-cost, innovative way to let students apply their knowledge of developmental biology in a creative, unexpected way.

SUPPORTING MATERIALS

- S1. Myth – Student handout
- S2. Myth – Presentation example with script
- S3. Myth – Student presentation

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Table 1. Lesson timeline. The lesson best spans a semester-long laboratory, with a brief check-in each week to see if the week's content is relevant to a student's mythological creature. Some independent student activity is required to prepare the presentation for the final lab presentations.

Activity	Description	Estimated Time	Notes
Preparation for Class (if virtual)			
Mythological Creature Identification	Have students open their lab kits (if virtual)	2 minutes	If this activity is used in-person, mythological creatures can be handed out during Class Session 1.
Class Session 1			
Introductory Lecture	Describe the project and its goals	10 minutes	Project goals are listed in "Introduction of the Project" in the Lesson Plan, and grading rubrics are posted in the learning management system.
Class Session 2 (repeated most weeks)			
Observations	Data collection	5 minutes per week	Have students relate their mythological creature to the week's learning topic. How is the week's topic relevant to their mythological creature? This class session is repeated each week until students have interacted with all lab content.
Class Session 3 (recommended)			
Chimera Introduction	A lab focused on how chimeras are formed	60–120 minutes	Because many mythological creatures are chimeras, a focus on how chimeras are constructed is recommended. This instructor uses neural crest chimeras as an example, as many of the mythological chimeras could plausibly include ectodermal placode transplants.
Class Session 4			
Student Presentations	Presentations of mythological creatures	5 minutes per student	Have students present their hypotheses for their mythological creature's origin.

Table 2. List of potential mythological creatures. Reasonably priced (<$15) "specimens" were acquired for the following mythological creatures and distributed, one per student. Specimens can be included in virtual lab kits or handed out during the first lab session.

Creature	Anatomical Description
Manticore	Lion body, human head, scorpion tail
Pegasus	Winged horse
Griffin	Half-eagle, half-lion
Centaur	Half-man, half-horse
Cockatrice	Rooster body, dragon wings
Owlbear	Bear body; owl head and talons
Hippogriff	Horse head and hind legs; eagle neck, front legs, and wings
Cyclops	Large, human-like creature with a single eye
Cerberus	Three-headed dog

Table 3. Presentation content rubric. Students received a copy of this rubric to help them make sure that they knew what material should be included in their three-minute thesis-style presentations.

Content	5 points	3 points	1 point
Introduction	Correctly identified your creature's atypical development	Incorrectly identified your creature's atypical development	No attempt to identify the atypical development
Hypothesis	Correctly identified how atypical feature(s) could have arisen	Attempted to identify how the atypical feature(s) could have arisen	No hypothesis or aim
Evidence	Found evidence that supports the hypothesis	Found evidence, but it may not quite support the hypothesis	No attempt at finding evidence

Table 4. Presentation style rubric. Students received a copy of this rubric to help them develop their oral presentation skills while practicing their three-minute thesis-style presentations.

Presentation Aspect	3 points	2 points	1 point
Slides	Well-formatted, easy to follow	Somewhat well formatted, a bit hard to follow	Distracting visuals, hard to follow
Oral Presentation	Well-paced, with appropriate volume	A little rushed or too slow, or perhaps too loud/soft	Rushed or very slow, or inaudible/ shouted
Transitions	Clear transitions between slides	Some transition between slides	No transitions between slides
Timing	2:45–3:00	Ran 15 seconds over or under	More than 15 seconds off
Q&A	Was able to answer* questions	Could answer some but not all questions	Was unable to answer questions

*Students are reassured that "I'm not sure" can be the beginning of a great answer and encouraged to take it a little farther: "I'm not sure, but I think I could find the answer in X" or "I don't know, but based on Y, I think that Z might happen."