Erich Fleming - Sabbatical Report 2019

I worked on three separate projects during my sabbatical (Spring 2019) that contributed to improving both my scholarship and my teaching. The main project involved the development and testing of an algal bioreactor to be used in my personal research program. In addition, I worked on an illustrated textbook for my interdisciplinary Art/Biol 389 course and developed an active learning project for my lecture-based classes.

Part 1 – The Algal Bioreactor

In 2016, I decided to pursue a new research pathway. I had been struggling with developing a research program at CSUCI that was technically simple enough to be accessible to most undergraduate biology students but complex enough to support a wide variety of research pathways for many years. I opted to focus on an old research interest of mine, algal biofuels and bioreactor design.

I developed a bioreactor concept that potentially solves a few major issues with growing algae for biofuel production. Biofuel generated from algae has been done, however the primary issue remains the expense. Typically, algae are grown in a standard bioreactor designed to promote growth and build biomass. The algae are then pumped to a separate chamber where certain nutrients are absent. In this chamber algal growth is inhibited but the cells remain active as they produce oils as a storage product. The algae are then concentrated using centrifugation or filtration. Lipids are then extracted from the concentrated algae. The pumping of liquids and the concentrating of the algae are both expensive processes. My design is a one chamber system that utilizes localized mixing to spatially separate regions of mixing and conditioning as well as takes advantage of gravity to partially concentrate the algae before harvesting.

For two years, I have had students working on my bioreactor concept without an actual bioreactor. Students worked on developing methodology, testing the air bubbling system, trying different media recipes, and measuring settling rates under varying conditions. I found that, even though the system is technically simple in design, students had difficulty envisioning the bioreactor system they were testing. I recognized that I needed to generate a prototype reactor that students could test and ultimately optimize.

The first series of experiments I performed tested the mixing system of the bioreactor. My bioreactor design uses one elongated cylindrical chamber that is divided into two sections by a bubbling apparatus situated halfway down the chamber at the end of a rigid tube. As the bubbles leave the tube they mix the medium as they rise to the surface. This creates a mixed zone in the upper half of the cylinder. Below the bubbling apparatus will be a zone of unmixed medium. In the mixed zone, algae will be kept in suspension under optimal nutrient and dissolved gas conditions. In this zone, growth will be optimized. When algae fall below the zone of mixing they will sink to the bottom of the chamber as there will be no bubbles to keep them in suspension. That is the main concept of the bioreactor. It is based on well-established principles but was untested. I needed to determine if algal cells could be maintained in suspension indefinitely or would incremental dilution deplete the mixing zone of all algal cells. To test the basic mixing system, I needed an abiotic stand-in for algae. Algae grow and thus

would add cells to the mixing zone even as they are diluted by sinking below the mixing line. Typically, microbeads are used for test such as this but they are very expensive. I found an alternative in soil. Soil is made of mineral particles of varying size. I used a system of sieves to separate out mineral particles about the same size as algal cells. Soil minerals are denser than algal cells so they would sink more rapidly than algal cells. Therefore, any measurements I take would be a conservative estimate of the mixing capacity of the bioreactor system. I added 20 g of soil (50-100 um diameter particle size) to a 2 liters of water in an acrylic cylinder (4 inches diameter; 20 inches tall). The bubbling apparatus was an acrylic tube (1/4 inch I.D.) with hole drilled into one end. The end with drill holes was capped with a small disc of acrylic. The acrylic tube was attached via a rubber hole to a low pressure air pump used for aquaria. I bubbled the soil mixture for about one month before ending the test. At least half of the minerals remained in suspension during that time. Soil minerals did collect at the bottom of the chamber indicating that some of the minerals dropped below the bubbling manifold and exited the mixing zone. This was just a qualitative or "proof of concept" run, but it appeared my bioreactor concept could work.

The next step was to build a fully functional prototype. Figure 1 shows an early rendering of the bioreactor and represents a more advanced version. Contrary to the bioreactor design depicted in Figure 1, the prototype I built was a flat-bottomed cylinder, with a manifold-cap that included only one input for air. I constructed the first prototype bioreactor out of acrylic plastic. Acrylic is easy to manipulate and bond together. Cleaning can be difficult as it is easily scratched. However, I knew I could wash acrylic in a mild acid bath if needed. Acrylic also has a melting temperature of 160 °C but a softening temperature of 110 °C. This is an issue if I want to use an autoclave to sterilize the bioreactor as autoclaves must reach 120 °C for a prolonged period of time to sterilize the bioreactor. There are other methods of sterilization such as germicidal lamps, ozone baths, and ionizing radiation but I do not have easy access to that equipment. I therefore conducted a test run on a full bioreactor prototype. I sterilized the bioreactor at 120 °C but limited the sterilization period to only 10 minutes. The acrylic in the bioreactor softened enough for the cylinder to collapse upon itself. I concluded I needed to make the bioreactor out of alternative, more thermostable, materials. After doing a little research and online shopping, I designed bioreactor 1.2. I constructed the bioreactor using a cylindrical glass vase (24 inch tall, 4 inch diameter) for the main growth chamber. I used polycarbonate plastic to build the bioreactor cap and bubbling tube. Holes were made at the bottom of the bubbling tube using a heated 24-gauge needle. Polycarbonate has a melting temperature of 225 °C and a softening temperature of 150 °C. Polycarbonate is more difficult to bond together but can be done using epoxy glue. This version of the bioreactor survived autoclaving without any deformation or failure of structural integrity.

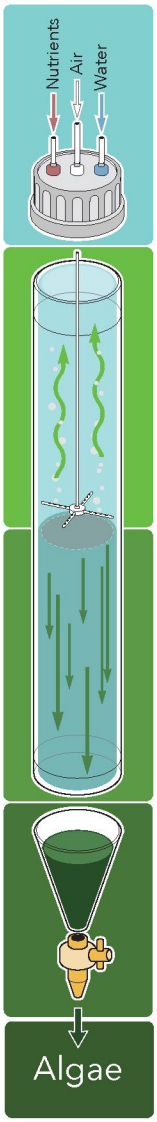


Fig. 1 – Prototype bioreactor design

I then set up a trial run of the bioreactor with live algae. The bioreactor was filled with 2.5 L of Bold Basal medium and then autoclaved

together. The bioreactor was placed 20 cm in front of a white LED array that generated 5 W/cm^2 of light. The alga *Chlorella vulgaris* was added to the chamber. Air was pumped through the bubbling tube and passed through a 2 um pore sized filter to filter out airborne bacteria. I ran the bioreactor continuously for one month. Some algae remained in suspension the entire time period. The algal concentration increased in the mixing zone and then appeared to stabilize. Algae fell below the mixing zone collected at the bottom. A white film developed on the surface of the concentrated algae at the bottom of the bioreactor. Its appearance was consistent with bacterial contamination. Microscopy analysis showed that bacteria were present in the algal concentrate but at similar levels as that found in the mixing zone. Water evaporation was an issue. Approximately 200 mL of water were lost over on month. Sterile water can be easily added to the bioreactor overtime to mediate this issue.

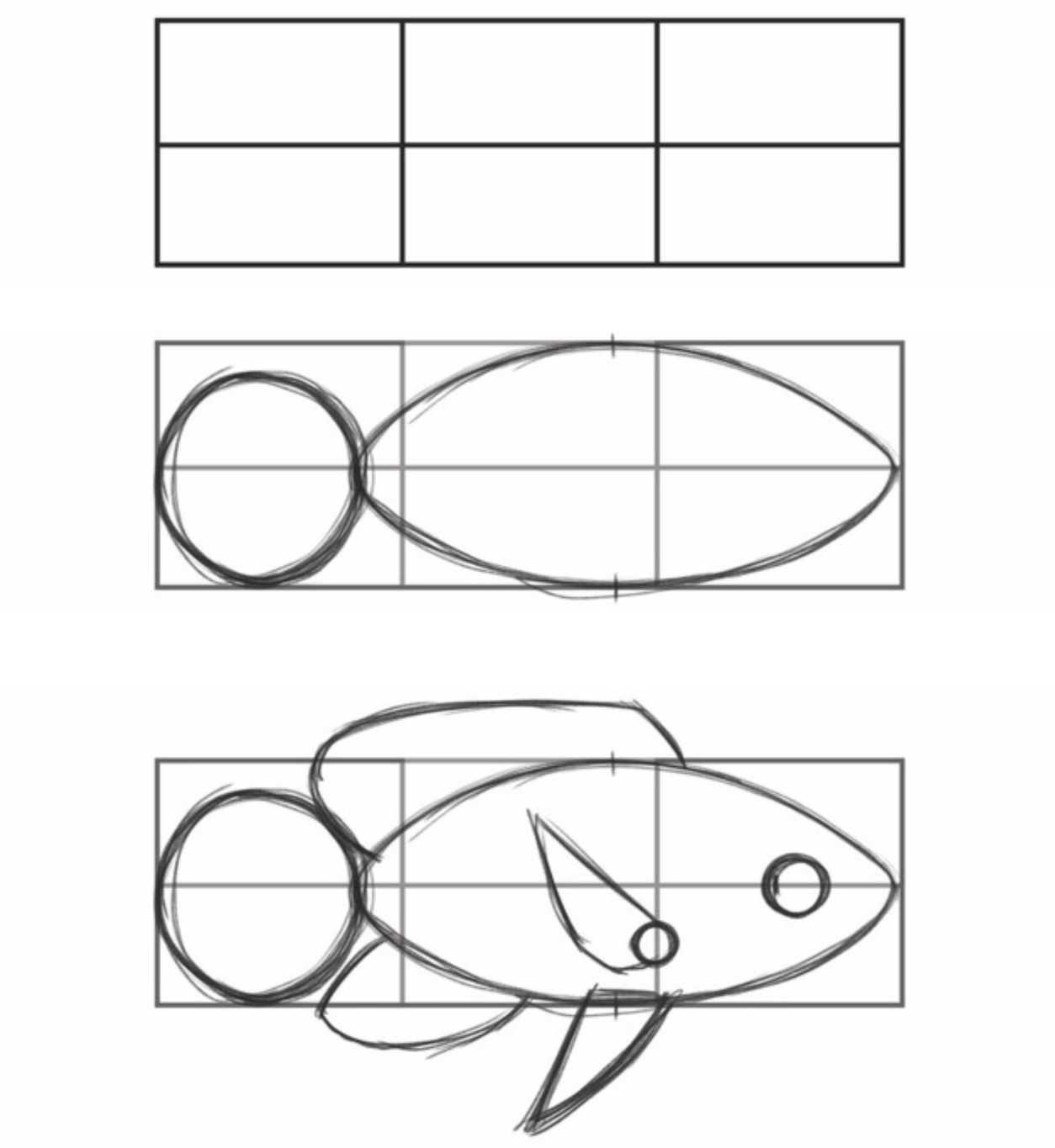
In the end, I accomplished my main goal – to build a working prototype of the bioreactor concept and show that design is functional. My research students have been working with this bioreactor during the fall semester and have been making measurements and following the growth characteristics of the algae in the bioreactor.

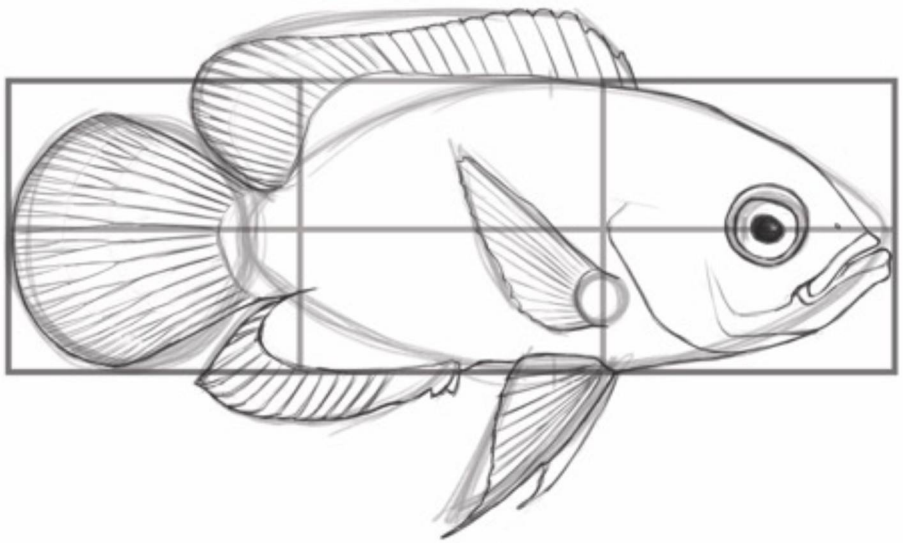
Part 2 – The Textbook

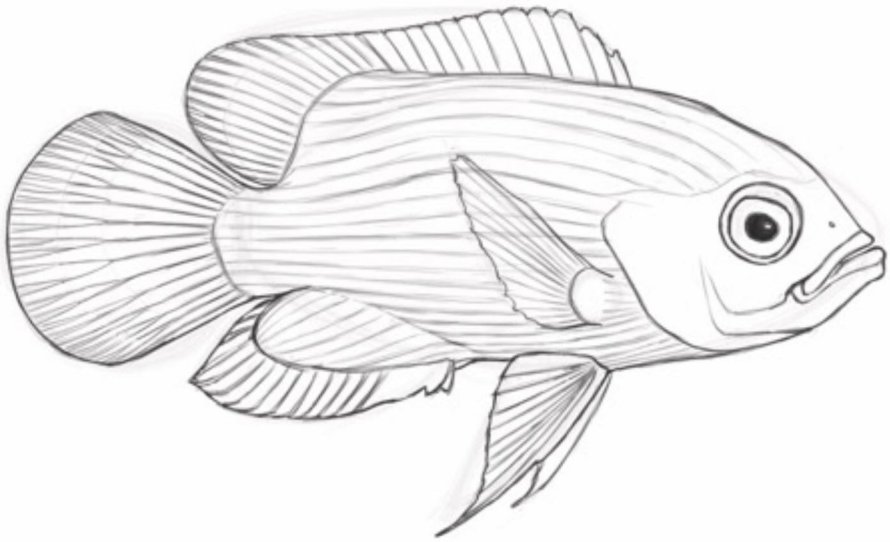
Art/Biol 389: The Science of Art and the Art of Science is, on the surface, a scientific illustration course. However, it is more accurately described as a combination of courses including a drawing methods course, a biological taxonomy course and a critical observation course. This kind of interdisciplinary course is powerful but rarely taught. Art students with interests in the natural sciences rarely have the opportunity to learn, for example, bird taxonomy or plant physiology. Biology students almost never take a course on Art and, in fact, are typically afraid of drawing. Critical observation skills are prized in the sciences but scarcely taught at the undergraduate level. Art/Biol 389 is an immersive interdisciplinary course that helps cultivate critical observation and critical thinking through art-based activities and the production of scientifically accurate artwork. It provides an chance for Art and Biology students to broaden their perspective and interact with other students from a different field.

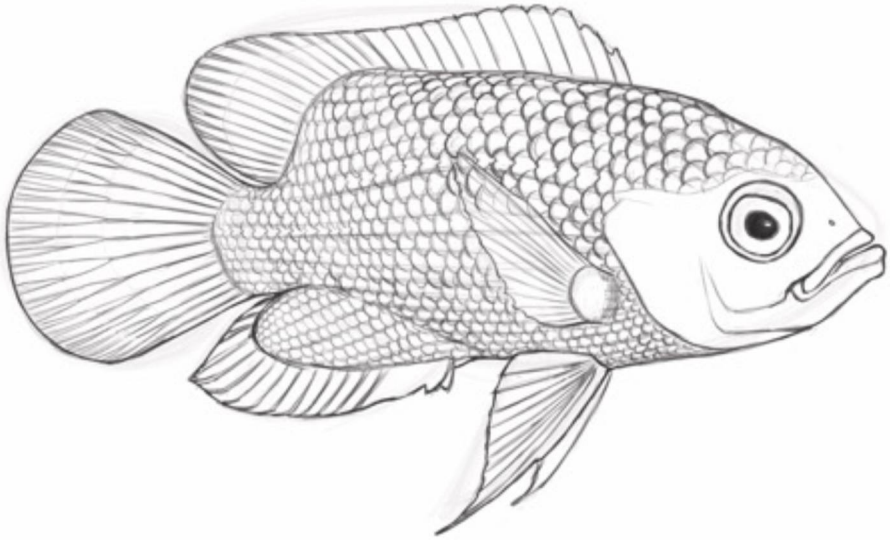
Needless to say, Art/Biol 389 attracts a broad range of students. We have taught first/second year art majors, third/fourth year art majors, biology majors with some drawing experience and biology majors that have never drawn in their life. Nearly every student is outside of their comfort zone when they take our course. Designing a course that can effectively reach all of these students has been difficult but we feel we have created an inclusive course by incorporating a number of high-impact practices and a lot of personal interaction with each student. During a standard class period, one of the instructors will lead the students in a two-hour, step-by-step, drawing activity at the front of the classroom while the other instructor moves around the class to offer personal instruction. While most art courses involve a short lecture followed by a free-drawing period, we have found that this form of instruction does not work well for our students. Since this is the first drawing course for most of the students, they lack basic drawing skills and do not benefit much from a free draw session. They require, and respond positively to, repeated and prolonged step-by-step demonstrations of techniques. I have observed that many unexperienced students have trouble

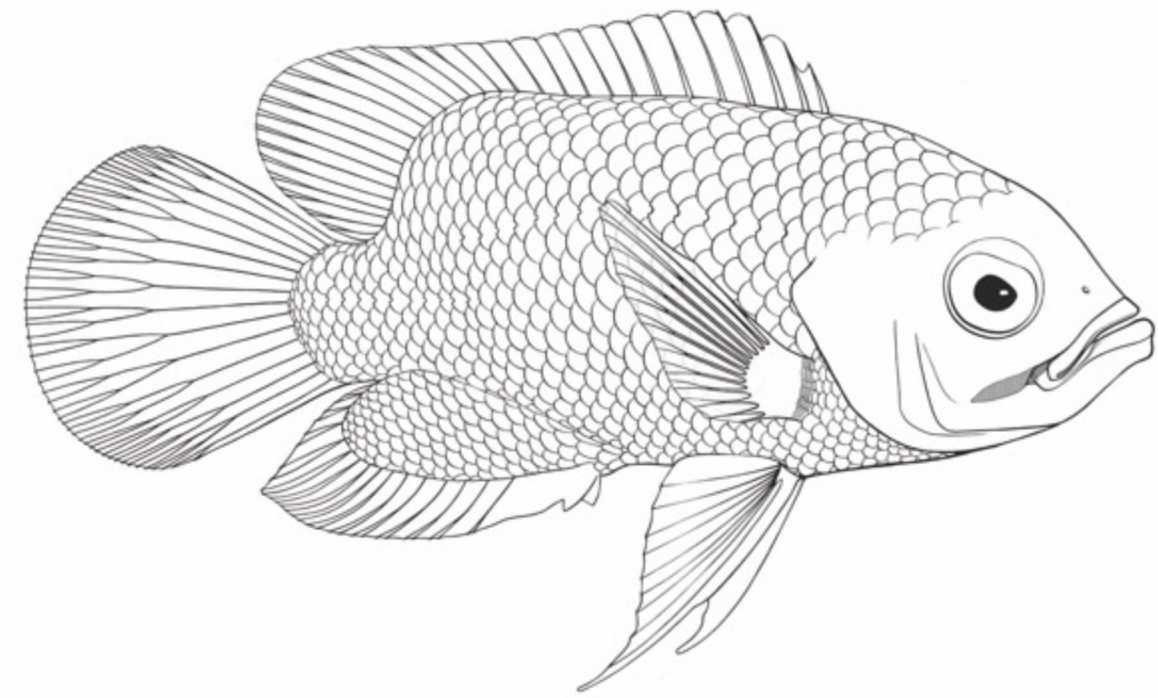
following along during class and quickly forget the drawing steps covered in our lesson plans when they work on homework assignments away from class. There are a number of scientific illustration textbooks on the market we could use in this course. Unfortunately, they are too specific in scope or advanced in methodology. Therefore, Liz King and I decided we needed to design and write a textbook specifically for our course that covers in detail the activities and lessons we cover. This requires creating a substantial amount of original artwork. Below is a collection of artworks I generated for this textbook.

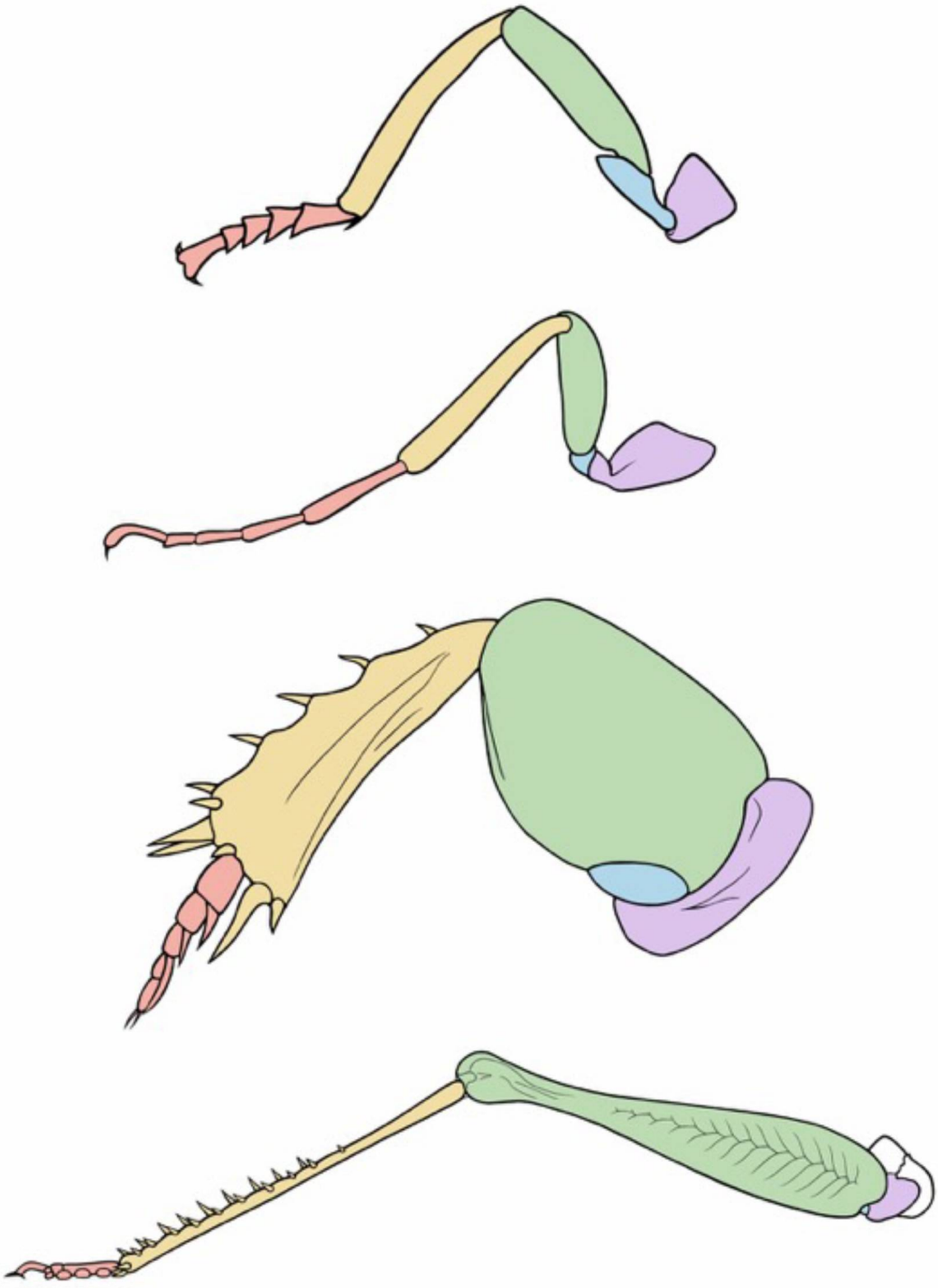


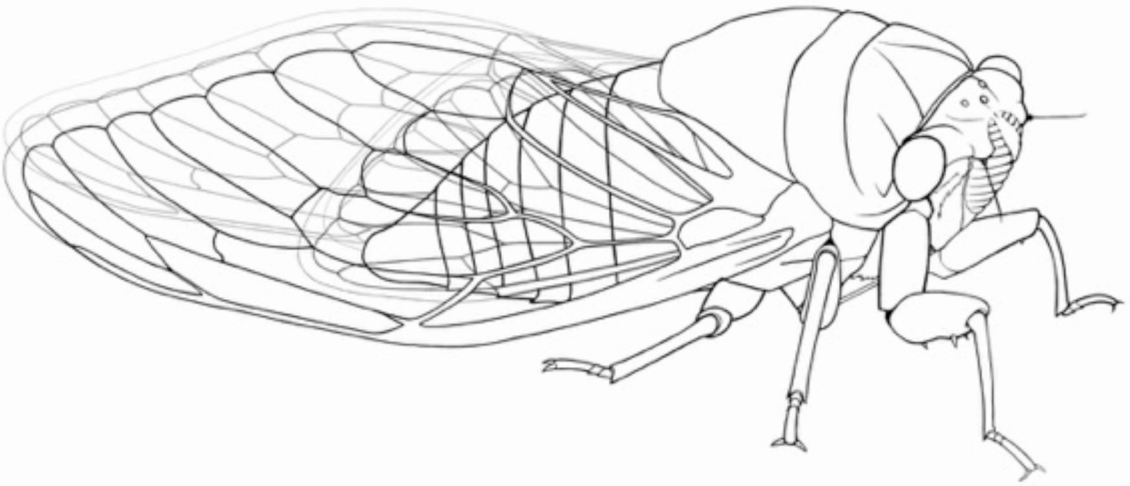


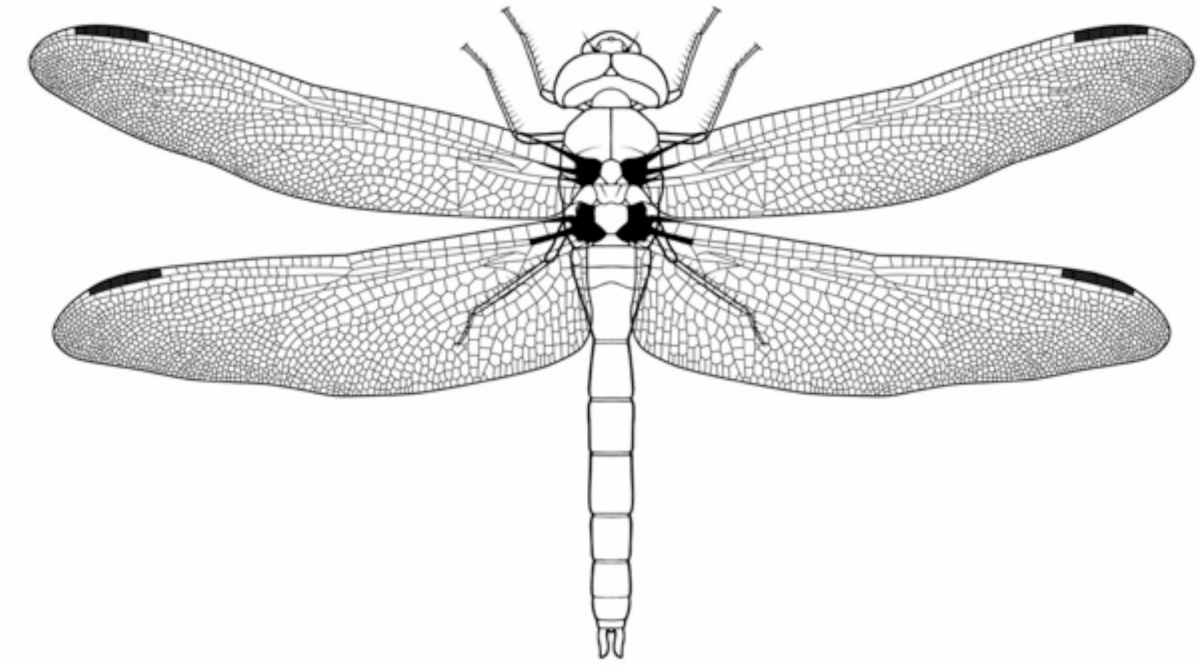


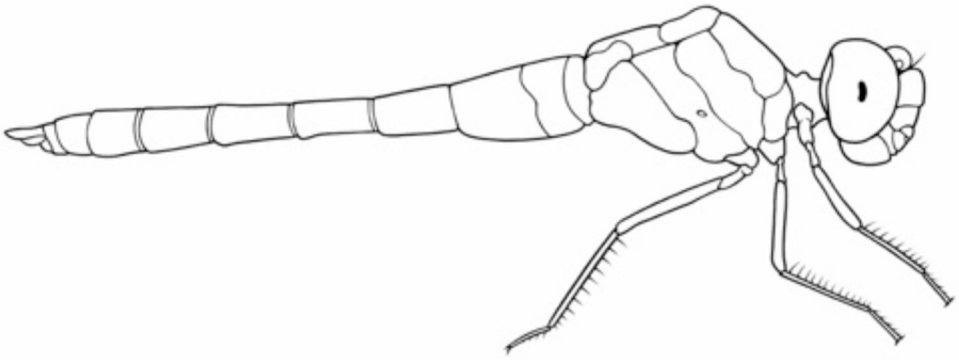


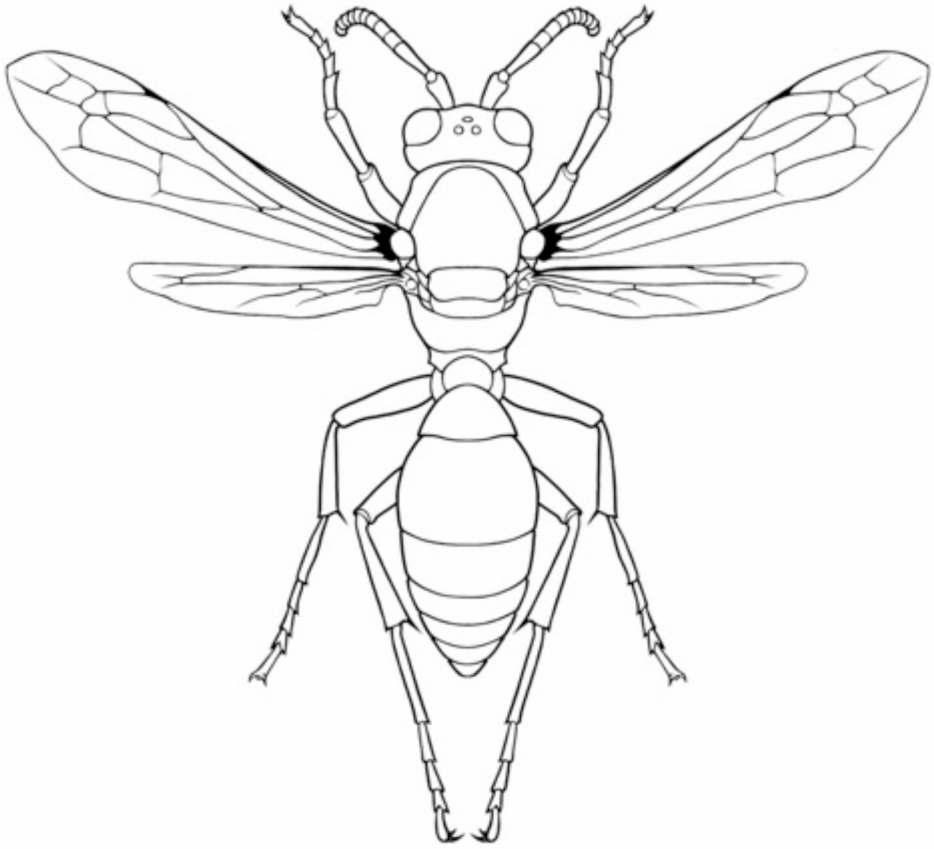


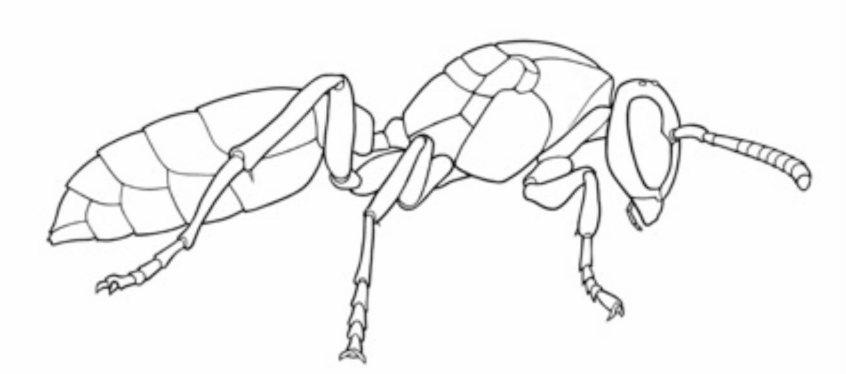


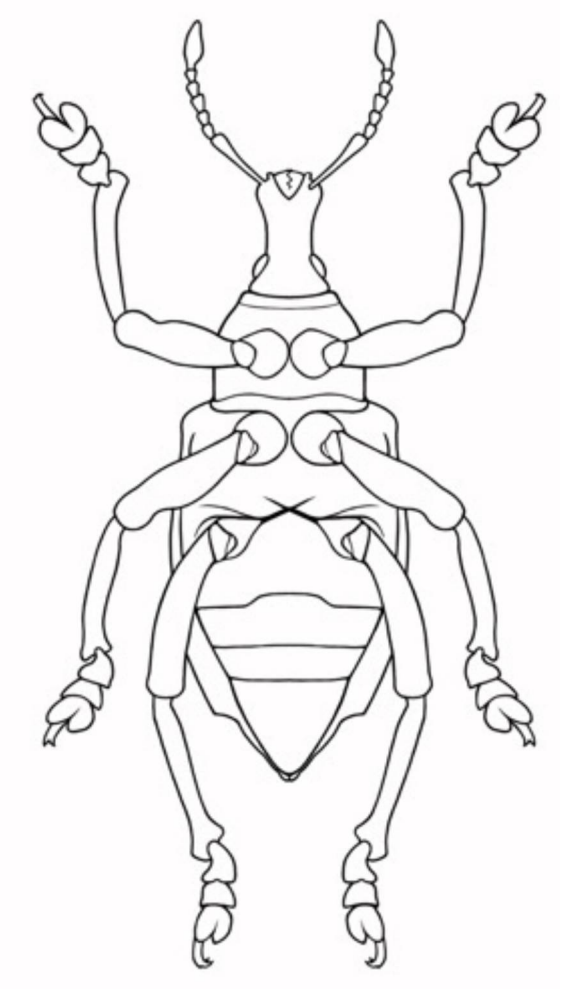


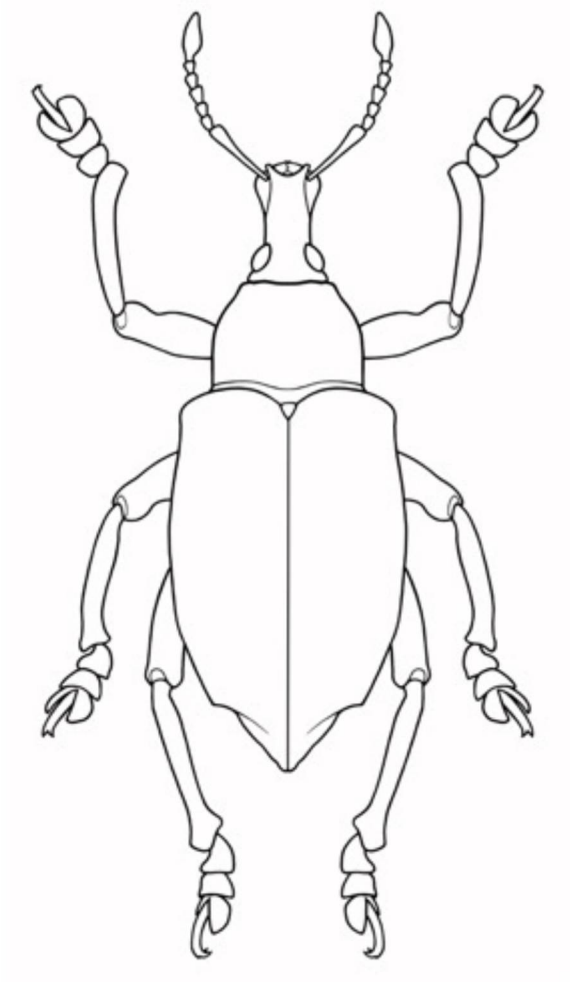


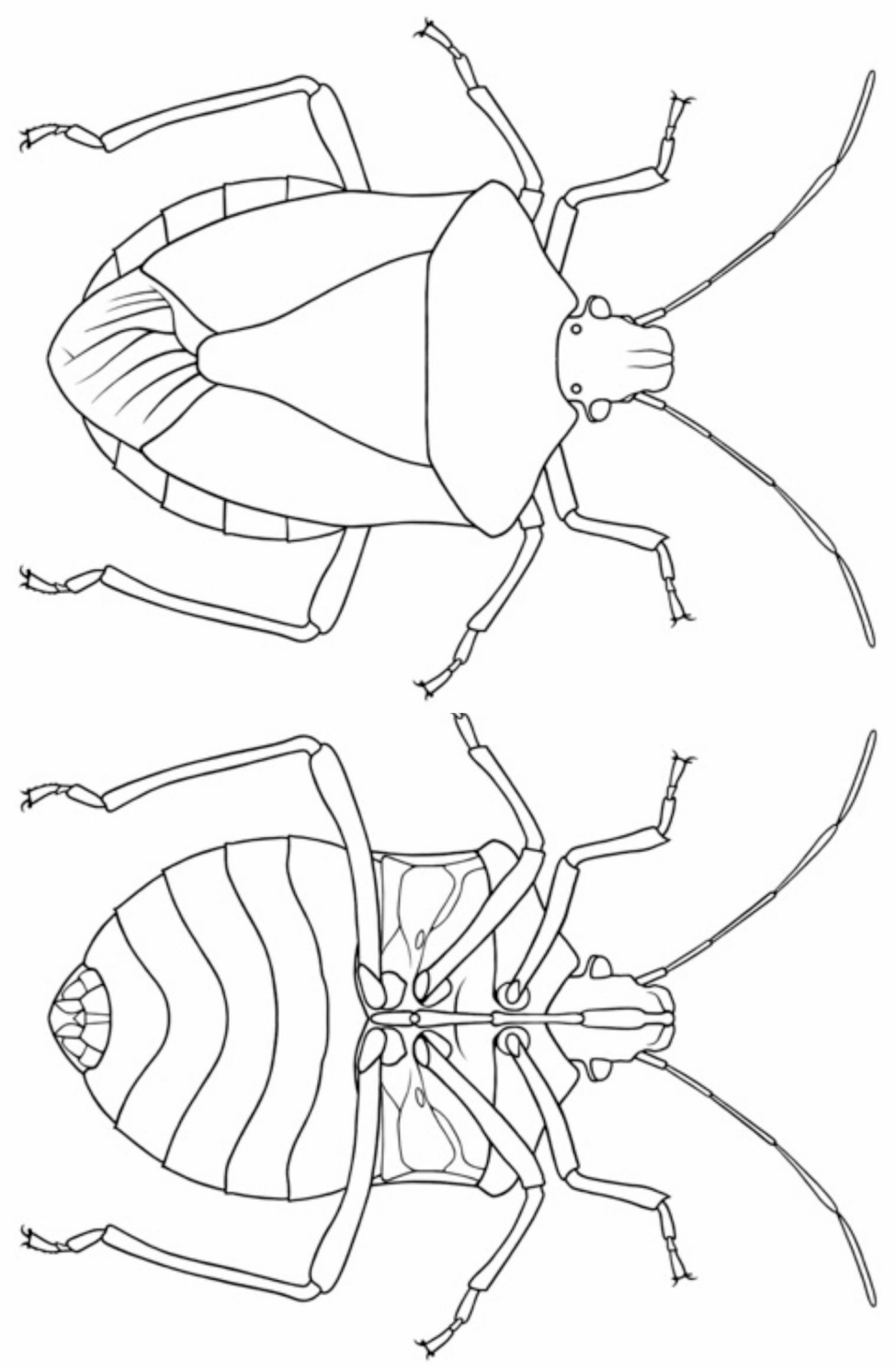


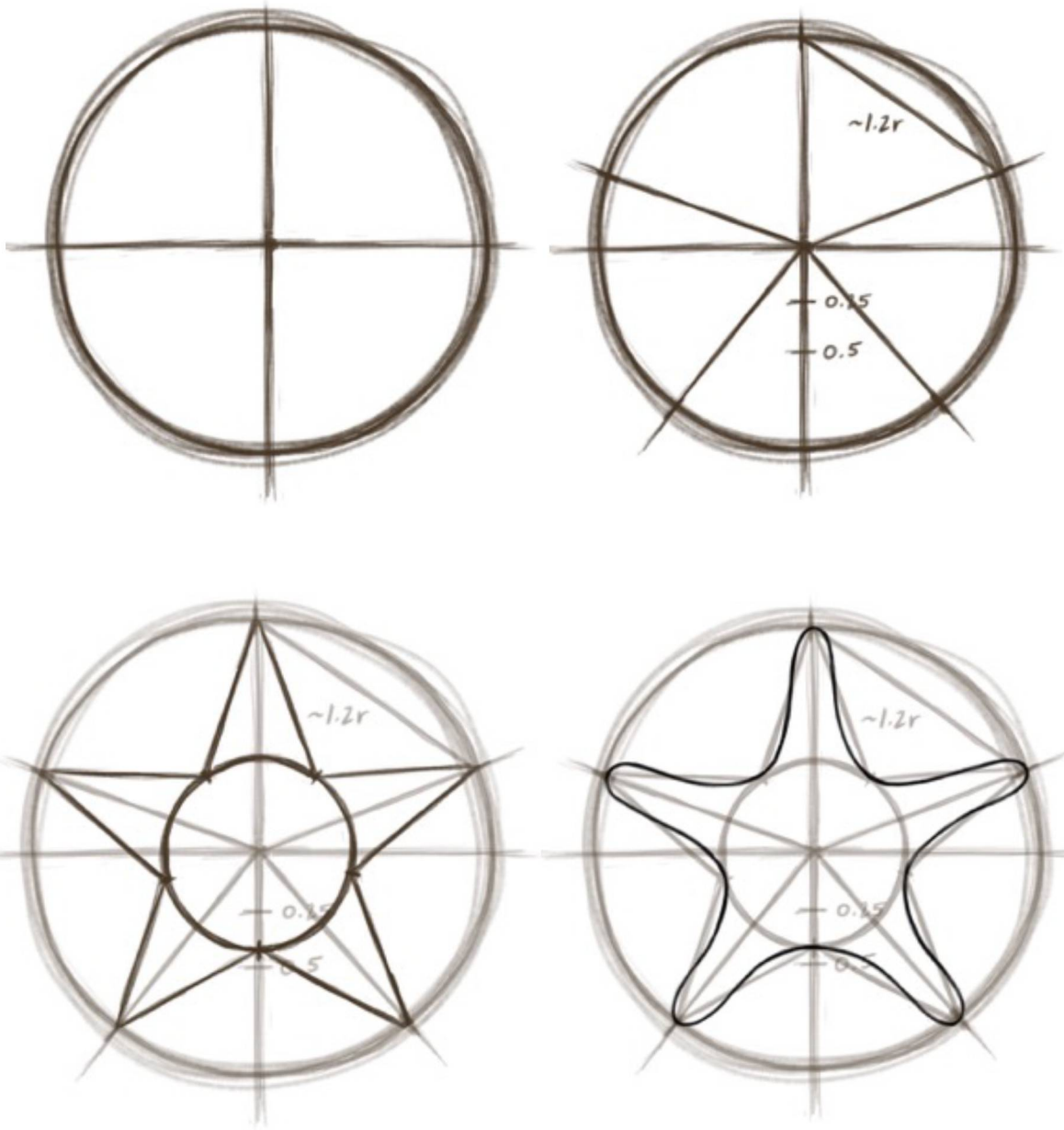








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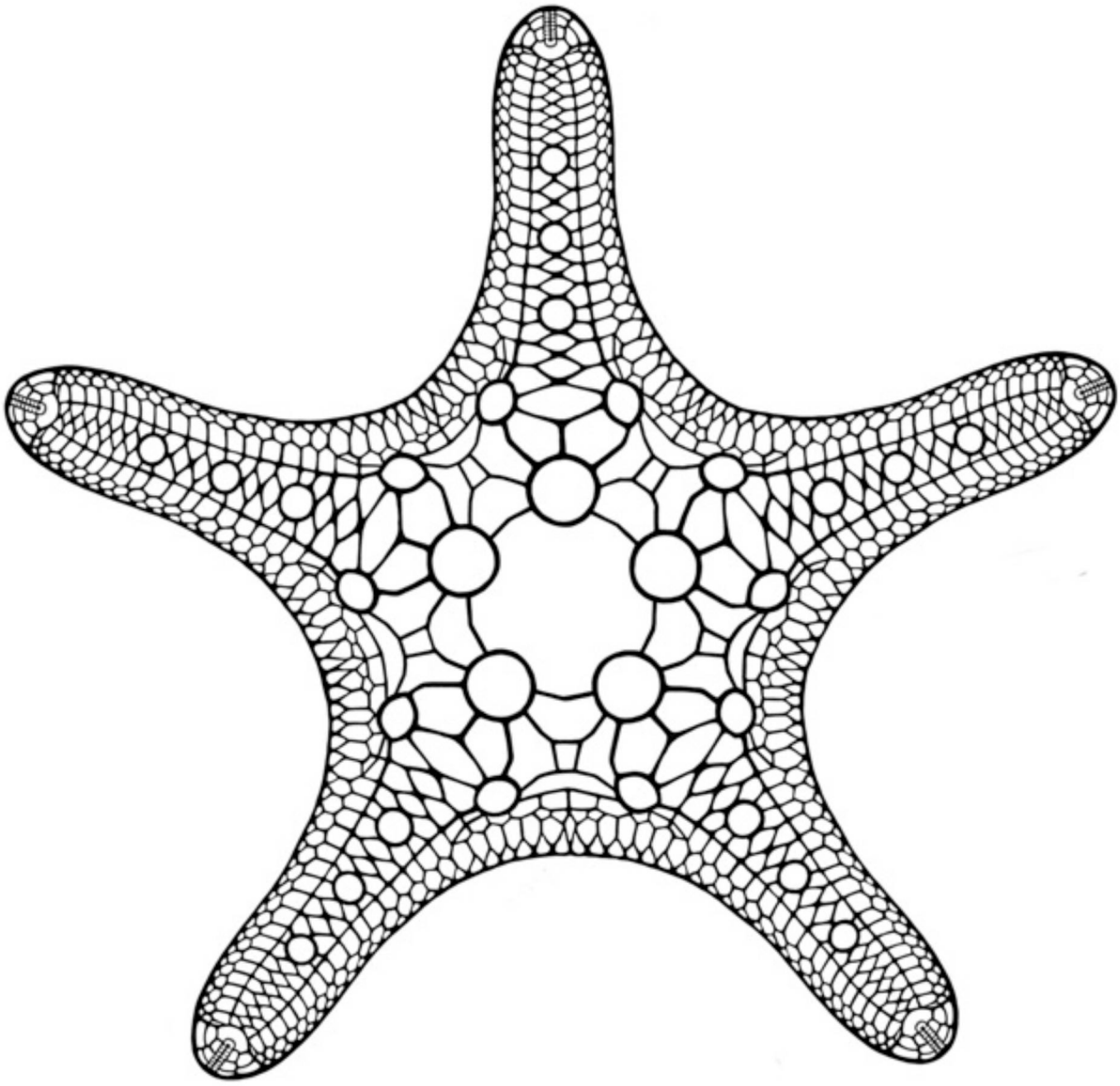

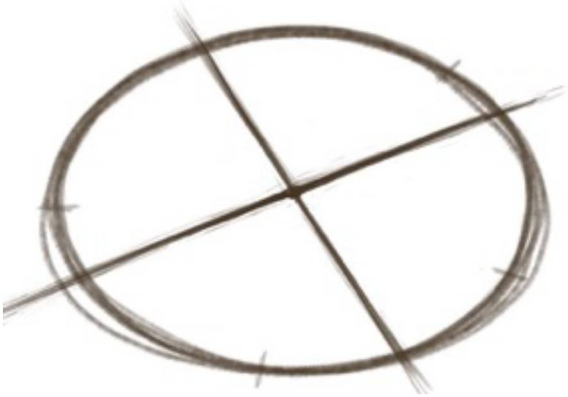

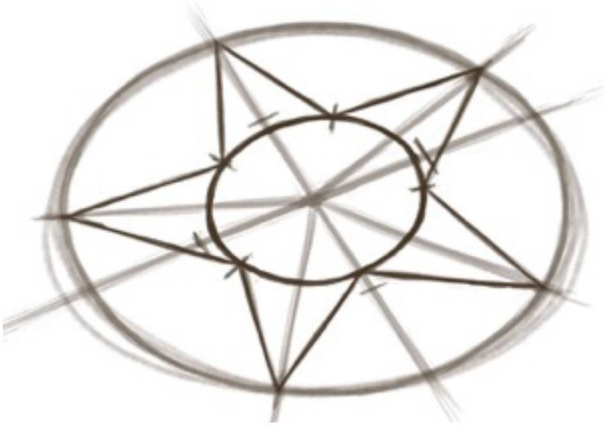

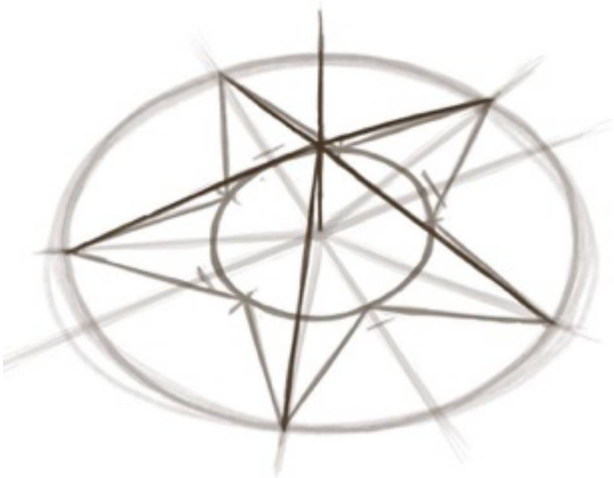

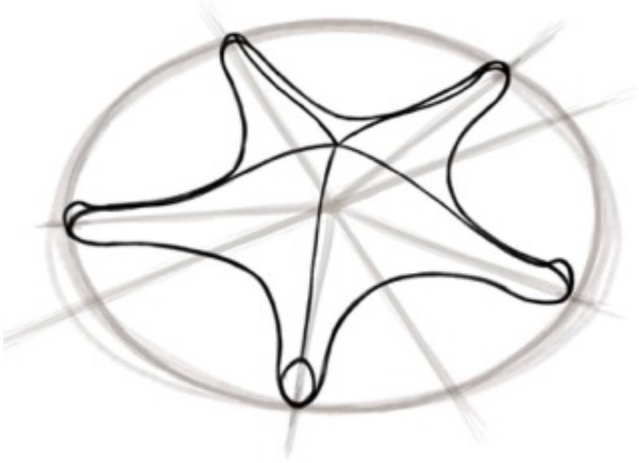

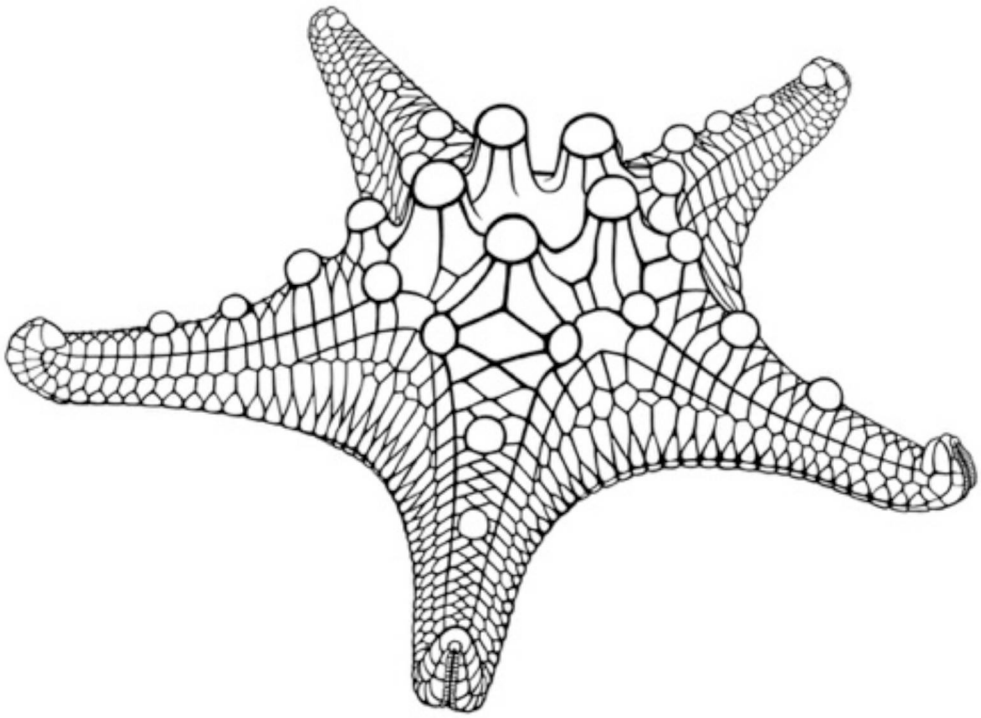

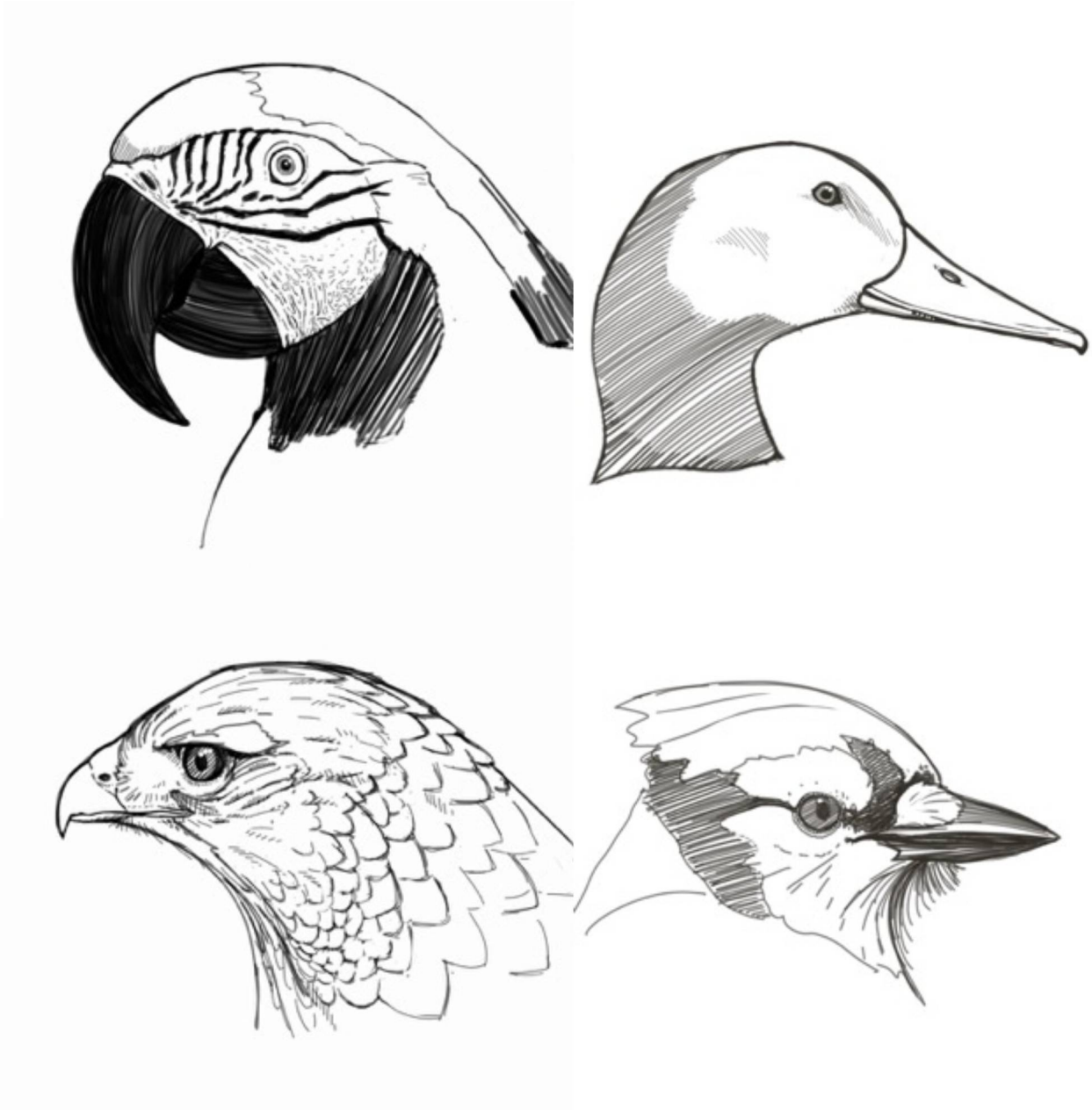

Part 3 - The Extra Credit

I did not plan on working on this project. The idea popped into my head during my sabbatical and I felt compelled to develop it for my Microbiology course. Students always ask for extra credit and I am always reluctant to give it to them. I want my students to prioritize studying, learn the material and do well on the exams, and not overly rely on extra credit assignments to make up for a lack of planning or effort. However, I have observed that students are willing to do a lot for extra credit even if it has very little effect on their grade. I also know that people respond well to a reward-based system like that used in video games and certain card-based games. I wanted to develop a system of extra credit that promoted independent learning as well as class participation. I designed an extra credit system based on class attendance. Every time a student arrives to class on time, they earn a "resource point." As the semester progresses and students collect "resource points" they can spend these points on activities to earn extra credit points. One method is to purchase a trivia question. During office hours, students are given a randomly generated question on all material covered so far in the course. The other method, called "Tasks," is to research a topic in the field of microbiology and write an essay with cited references. I have a list of topics that are randomly assigned when requested by students. The last aspect of the extra credit system is "Bonus cards." Bonus cards are earned when students have perfect attendance between exams. Bonus cards are modifiers of the Trivia and Task systems. For example, students can redraw trivia questions or task topics. I have implemented the extra credit system this semester (Fall 2019). The new system appears to be well received although it has taken time for students to understand how it works. About 80% of the students have participated and nearly every student has traded in resource points for tasks rather than trivia questions. I am pleased with this result, as I wanted to promote outside learning to complement what is covered in class. Below are the rules for the extra credit system.

Science the Gathering... of extra credit

"Science the Gathering... of extra credit" is a randomized, card-based, award system for Microbiology (Biol 301). Participation is voluntary and opting out will have no adverse effect on your grade. However, participating will give you the chance to earn extra points toward your course grade.

Students have the opportunity to acquire cards that will contain trivia questions, scholarly tasks or event specific awards. Trivia cards and task cards have point values which, if successfully performed, will be awarded toward the student's course grade. Bonus cards are primarily modifiers of trivia and task cards.

Resource Cards (Fleming Fun-Bucks)

Resource cards are used to trade in for trivia cards and task cards. Trivia cards are worth 5 resource cards, and Task cards are worth 10 resource cards. Students earn resource cards by

attending class on time. Roll will be taken at the beginning of every class. If a student arrives after roll is taken, they will not earn a resource card. Please note, Dr. Fleming's proficiency in taking roll will increase with each iteration. Resources card accounting will be performed by Dr. Fleming.

Trivia cards (Cards of Randomized Testing of Scientific Knowledge)

Trivia cards contain one question pertaining to the material covered in class as of the day the trivia question is asked. Students have 2 minutes to answer the trivia question. Trivia cards are worth 2 points if answered correctly. Trivia questions can be asked during class or during office hours. In addition, if a bonus card is to be used during a trivia event, the question must be answered during class. If any trivia question is answered incorrectly, no points will be awarded. There is no partial credit on trivia questions. The scope of a trivia question will vary (true/false to short answer).

Task cards (The Box of a 100 Tasks)

Each task card has a different topic or question related to Microbiology. Task cards are potentially worth 5 points toward your lecture grade. To earn full credit, you need to research a question/topic and then write a one-page, single-spaced essay. In addition to the one page, you need to provide a bibliography listing all the resources you used to research the article. The article will be graded on grammar/spelling, thoroughness, and accuracy. Each article will be posted on the course website.
Only one task card can be played in between exams. This means you cannot give me all your task cards on the last day of class.

Bonus Cards (Deck of Finite Possibilities)

Bonus cards are modifiers of resource, trivia and task cards. Bonus cards can be earned by achieving perfect attendance in between exams.

FAQ

1) Q: Can I trade cards with another student?

   A: Yes, as long both cards are of the same type and of equal value: one task card for one task card or one bonus card for one bonus card.

2) Q: Can I buy a card from another student?

   A: No. I will be keeping track of every student's cards. If you try to use a card not acquired using resource cards, I will not honor it.

3) Q: What happens if I lose a card?

   A: Its lost. This is only applicable to bonus cards.