Backyard Evolutionary Biology: Investigating Local Flowers Brings Learning to Life

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Abstract

As college courses transition to online instruction in response to COVID-19 incorporating inquiry-based learning is all the more essential for student engagement. However, implementation can prove challenging for instructors. I describe a strategy for inquiry-based learning that is straightforward to apply in a variety of course modalities, including asynchronous and synchronous online courses. I describe an assignment where students explore the developmental basis of morphological evolution. Flowers offer an excellent example to address this concept and are easy for students to access and describe. Students were asked to conduct research on local flowering plants by collecting and dissecting flower specimens to determine their whorl patterns and then generate hypotheses to explain the developmental genetic basis of the patterns identified. This task allowed students to apply their scientific thinking skills, explore nature, and connect their understanding of the developmental basis of evolutionary change to everyday life. I designed this assignment to be completed asynchronously, and it can be easily modified for synchronous online and traditional face-to-face meetings. Incorporating inquiry using readily available, tangible, tractable real-world examples is a pragmatic and effective approach during and beyond COVID-19.

Keywords: Inquiry-based learning, Evo-devo, flower whorls, hands-on science

Introduction

Inquiry-based learning and active engagement are essential for students to retain course material and develop analytical and critical thinking skills (Handelsman et al 2004, Freeman et al 2014). Implementing an inquiry-based curriculum can be challenging in the best of times and the constraints posed by the shift to remote teaching due to COVID-19 will make it even more so. Nonetheless, constraints breed resourcefulness, and here I describe a course assignment that provides a practical model for how instructors might incorporate inquiry-based tasks during COVID-19 posed restrictions and beyond. This model can be readily adapted to address a number of evolutionary biology concepts in a variety of learning modalities, including synchronous and asynchronous remote learning.

Evolutionary developmental biology (evo-devo) is an essential aspect of teaching evolution (Perez et al 2017). However, Hiatt et al (2017) found that evolutionary biology curricula typically address development superficially and that students lack adequate understanding of foundational concepts from developmental, cell, and molecular biology. This is also reflected in the fact that the literature on teaching and learning of evo-devo is sparse compared to subfields such as natural selection and phylogenetics (Ziadie and Andrews 2018). Therefore, I sought to design a curriculum to address this gap in teaching and learning of evolutionary developmental biology.

Next, I identified a compelling and readily available example of variation: flowers. Flowers are amazingly diverse in their color, size, shape, and smell. Flower whorl patterns are a particularly well-studied aspect of flower morphology. A typical flower of the model plant *Arabidopsis* is composed of four concentric whorls: sepals, petals, stamens, and carpels (Figure 1). The simplified ABC model explains the developmental genetic basis of whorl development. The expression patterns of four main classes of genes, called A, B, C, and SEP, are associated with the formation of specific whorls in *Arabidopsis* (Irish 2017). The number and arrangement of whorls vary widely and changes in the spatial expression patterns of ABC genes are associated with the changes in whorl patterns in different floral species. Therefore, flower whorl variation provides an excellent example to illustrate how small changes to gene networks and development can generate variation between species.

I developed an assignment where students conduct research on their local flowering plants by collecting and dissecting flower specimens to determine whorl patterns. Students then generate a hypothesis to explain the developmental genetic basis of the whorl patterns observed. These tasks sharpen students' scientific skills and connect their learning to the natural world around them.

Assignment Description

The assignment I describe was implemented in an upper-level genetics course at the Minerva Schools at Keck Graduate Institute. Minerva is a primarily undergraduate institution where students are in a global rotation program, living in different cities during the course of their studies. Courses are taught in virtual classrooms via video conferencing on our proprietary platform using active learning pedagogy. Each course includes a Location-Based Assignment (LBA) that engages students with their location of residence and connects it to their course work. This format is applicable in any modality and is particularly well-suited to accommodate COVID-19 related uncertainty when classes may be remote and asynchronous.

Students were tasked with first conducting a literature search on local flowering plants of the region they reside in and determining specific sites where they might access selected plants that are in their flowering season. I suggested some possible sites such as local parks, botanical gardens, nature preserves, local nurseries, and greenhouses. Students then visit their selected sites individually or in small groups to collect flower specimens. I asked students to ideally find an intact flower fallen to the ground, or obtain verbal permission to pluck a flower if needed. Students dissect the flower to determine its whorl patterns and record images of the intact and dissected flowers. I directed students to open access resources (e.g., How to draw a floral diagram, n.d.) to self-learn how to dissect the flower and draw a floral diagram.

In their submission students were asked to describe their selected plant, with a focus on adaptations that allow it to grow in the regional conditions such as climate, type of soil, and pollinator species. Students reported the flower whorl pattern, including images of the flower and floral diagrams (Figure 1). They proposed and justified a hypothesis to explain how changes in the expression patterns of ABC genes might lead to the whorl patterns seen in their flower as compared to *Arabidopsis*. I assigned students chapters from their course textbook, as well as open-source articles (Krizek and Fletcher 2005, Irish 2017) as resources for their research.

Outcomes

The assignment was successful in allowing students to connect their coursework to everyday life. In the end of term course survey, 83% of respondents agreed or strongly agreed with the statement '*The LBA helped me apply the course learning outcomes in real life'*. Selected student comments included '*The LBA was really great and fun. It was nice seeing how genetics applied to real life*' and '*Really enjoyed the hands-on aspect and looking at flowers'*

In a class of seventeen students, thirteen unique flowers were selected. The following student comment from the end of course survey illustrates an important consideration for specimen collection *'I really liked the assignment but I did get a bit disheartened when I was trying to find a flower in Berlin in December because there's not a lot of things flowering at that time of year. It did lead to some interesting research, though, *because* most things aren't flow(er)ing in December and this plant was* '. This is particularly relevant in light of restrictions due to COVID-19. While students may still be able to explore open natural areas, it is likely that access to sites like botanical gardens or greenhouses will remain limited. In addition, depending on the time of the year that the assignment is introduced, there may be fewer flowering species in the students' regions. Instructors can expand students' options for site visits to include local florists and grocery stores to research commercially available varieties. Students could also use applications such as iNaturalist to identify plant species in their backyards (iNaturalist, n.d.).

Most students accurately determined flower whorl patterns and effectively generated hypotheses based on the existing model of spatial patterns of expression of ABC genes. The assignment prompt was open-ended and students were not prompted to provide in-depth molecular explanations. When students did give detailed explanations these provided critical insight into their understanding. For instance, one explanation given for the increase in the expression domain of a gene was gene duplication. This explanation fails to account for the role of cis- and trans-regulatory elements in gene expression, a commonly held student misunderstanding (Hiatt et al 2017). Another common student challenge in developmental biology is recognizing the temporal aspects of development (Hardin 2008). Indeed, students' explanations did not effectively distinguish between the timing of expression of genes during bud development and adult flowers. To further probe student understanding instructors can explicitly prompt students to provide molecular justification in courses where students are expected to have this knowledge.

Conclusion

Observing and documenting flower morphology is straightforward and does not require extensive teacher or student training. Whorl patterns can be determined with the naked eye for most flowers, so it is a cost-effective activity with little need for equipment or supplies. The assignment described here can be adopted in evolutionary biology, genetics, and developmental biology courses as well. Investigations of local flowers and plants can also be considered more broadly for ecology and biodiversity courses. This assignment can be adopted as written for asynchronous course assessments, ideally with opportunities for scaffolded formative feedback from the instructor. It can also be modified for face-to-face or virtual synchronous meetings or laboratory courses. For instance, students can work in small groups and engage in peer instruction to compare whorl patterns and genetic models in curated specimens.

Feasibility, insufficient time, and logistical constraints pose major barriers for faculty to undertake large scale curriculum reform (Bronwell and Tanner 2017, Borcherding et al 2019). Adopting the model exemplified by this assignment and using examples that can be readily accessed for hands-on scientific inquiry can be very effective during COVID-19 and after.

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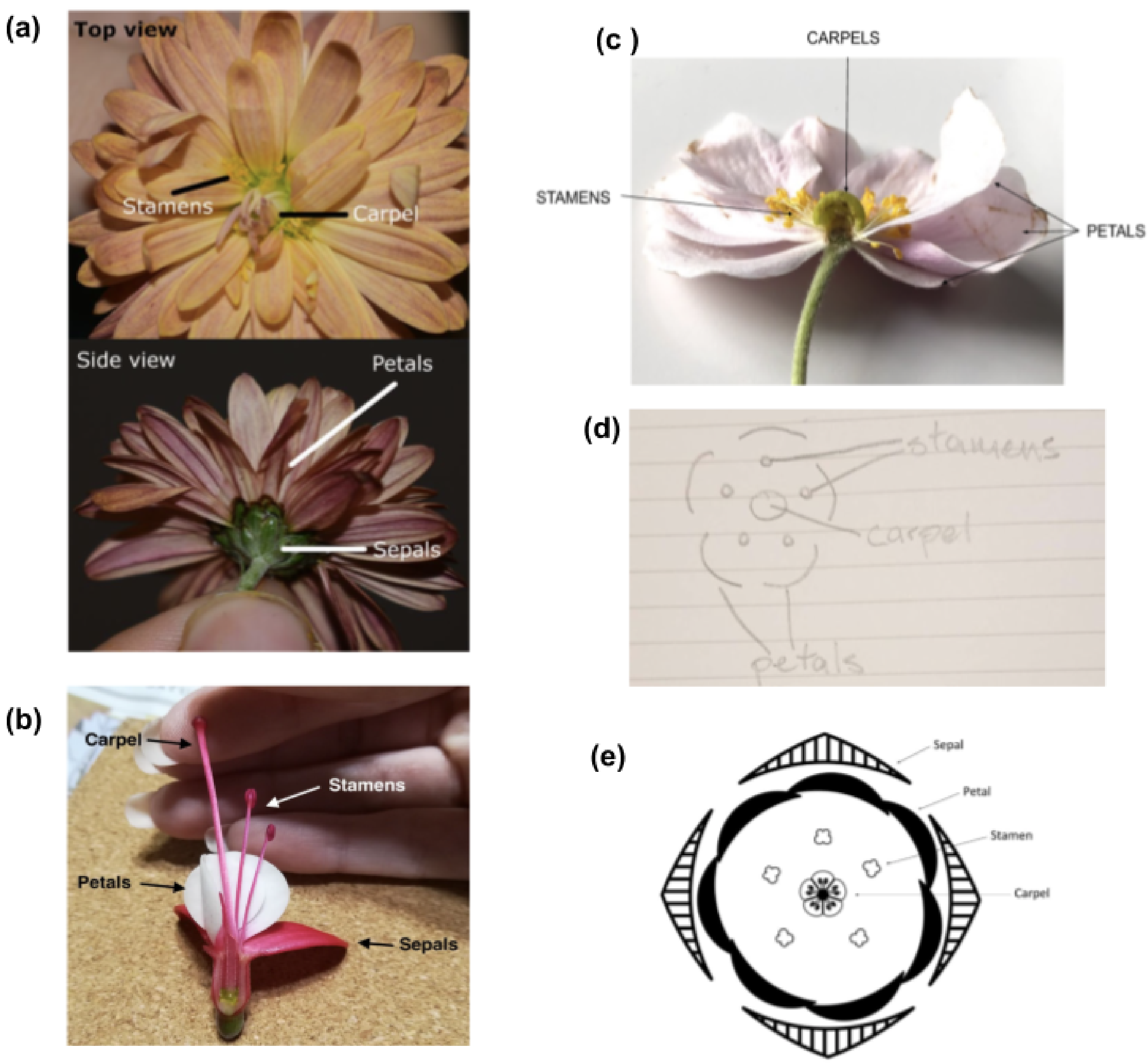
Figure 1: Selected examples from students' submissions showing flower whorl patterns (a) *Chrysanthemum morifolium* (b) *Fuchsia magellanica* (c) *Anemone hupehensis* (d) Hand drawn floral diagram of *Viburnum farreri* (e) Floral diagram of *Echium handiense* generated using Wikipedia's open-source graphics.



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