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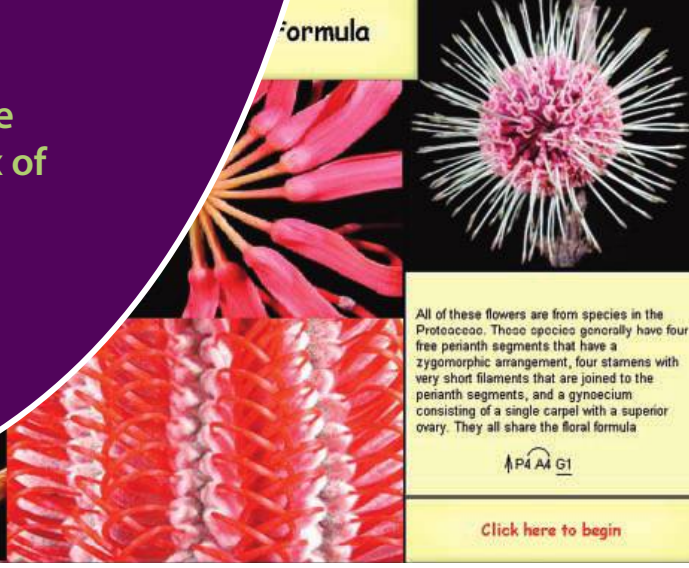
Teaching Flower Structure & Floral Formulae – A Mix of the Real & Virtual Worlds



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Abstract

The study of flower structure is essential in plant identification and in understanding sexual reproduction in plants, pollination syndromes, plant breeding, and fruit structure. Thus, study of flower structure and construction of floral formulae are standard parts of first-year university botany and biology courses. These activities involve developing a complex set of skills, and it is useful for students to review this material after practical sessions. The Virtual Floral Formula Web site provides students with a unique resource for practicing their floral structure interpretation skills. The site provides detailed dissection photographs of the flowers of 12 species, and floral formulae are progressively assembled via drop-down menus. When students are satisfied with their answers, they submit them, and any discrepancies from the "official" formula are highlighted. Students appreciate the interactivity of the application, the feedback they receive on any inaccuracies in their formulae, and the ability to make progressive improvements in their skills.

Key Words: *Flower; floral; structure; formula; formulae; virtual; dissection.*

Flowers and their resulting fruits are a distinguishing feature of the angiosperms. Flower structure is a core component of biology and botany curricula across the globe and is studied at increasing levels of detail as students progress from school to university. Ways to interest and involve students in the study of plants through flower structure have been suggested over many years (e.g., Bernadette, 1958; Flannery, 1987; Marquard & Steinback, 2009). An understanding of flower structure is important from many perspectives.

- The primary function of flowers is to facilitate genetic recombination. By understanding flower structure, students can appreciate diverse aspects of floral biology, such as how a species with perfect flowers can reduce self pollination and the different pollination syndromes.
- Understanding flower structure is the basis for appreciating fruit structure, including the differences between simple and aggregate fruits and true and accessory fruits.
- Understanding various aspects of plant breeding, such as artificial hybridization, depends on a correct interpretation of floral form and function.
- Surveys of plant diversity depend on accurate species identification, often based on an observer's assessment of flower structure. Although DNA barcoding of plants is considered workable (Ausubel, 2009) and portable DNA analysis devices for nonexperts have been suggested, plant species identification will continue to depend on interpretation of floral structure.

Floral formulae are a shorthand way of summarizing the main features of a flower.

Floral Formulae

Construction of floral formulae is a common activity in upper high school biology classes and a standard practical activity in many first-year university biology and botany classes. Floral formulae are a shorthand way of summarizing the main features of a flower (Clarke & Lee, 2003; Judd et al., 2008; Prenner et al., 2010). They have two main practical uses. First, when keying out a plant it is most efficient to fully observe a flower's structure, prepare a floral formula, and then progress to keying out. Almost all the features denoted in a floral formula will be used in the identification process just to get to family level. This is more efficient than returning to the specimen to reexamine it as each new pair of questions is encountered. Second, comparing the floral formulae of a variety of species in a family is an excellent way to find the main features of a family and the areas of variation, if any.

For better or worse, botanists have not standardized the format of floral formulae, although see the recent suggestions of Prenner et al. (2010). The three formulae in Figure 1 are for very similar flowers (*Fuchsia*, *Oenothera*, and the Onagraceae in general), but at first inspection they appear to be quite different. Some of the major differences in the formulae are related to the fact that species in the Onagraceae have a floral tube or hypanthium, and this structure is represented in quite different ways in the three formulae. Even allowing for these differences, it is relatively easy to decipher most of the botanical information contained within a floral formula, no matter what the format is.

A Unique Web Resource

The Virtual Floral Formula is a Web site that lets students practice their floral structure interpretation skills using detailed dissection photographs of the flowers of 12 species. It was constructed in ToolBook (SumTotal

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Systems), an e-learning development application that allows for interactive content. To access the site, go to http://www.csu.edu.au/herbarium/ and click on "The Virtual Floral Formula."

The 12 species that are used cover a wide diversity of the eudicots (Table 1). Each is from a different family, representing 10 different orders. Three of the samples – *Paulownia* (Bignoniaceae or Paulowniaceae), *Hebe* (Scrophulariaceae or Plantaginaceae), and *Eremophila* (Myoporaceae or Scrophulariaceae) – are from the Lamiales, and their floral formulae (Table 1) show some diagnostic features of this order, such as two-lipped zygomorphic flowers with two or four stamens (Judd et al., 2008). (Alternative family names for these genera are given above because the taxonomy of the upper levels of the Lamiales is in a state of flux; Judd et al., 2008.)

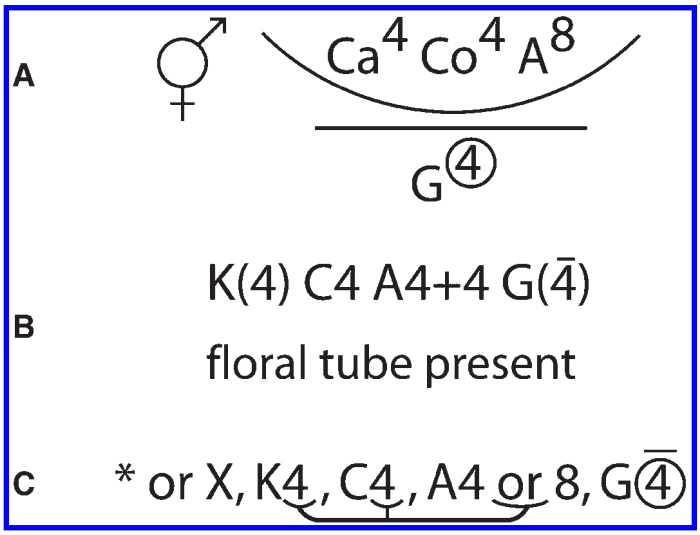

Figure 1. Floral formulae for a very similar flower structure from different sources. **(A)** *Oenothera* from the Digital Flowers website of the University of Illinois. **(B)** *Fuchsia magellanica* from Clarke and Lee (2003). **(C)** Onagraceae from Judd et al. (2008). Much of the apparent variation derives from the different ways the floral tube has been expressed.

After the opening page (Figure 2), which shows some of the floral diversity of the Australian Proteaceae (but with little or no variation in floral formulae), users progress to a page where they can choose between (1) learning about flower structure and floral formulae in general, (2) learning how to use the Virtual Floral Formula site, and (3) constructing their own floral formulae. Several aspects of interpreting flower structure are relatively straightforward (e.g., counting numbers of parts or determining whether the same types of parts are free from each other or united), but others, such as floral symmetry and gynoecium structure, are more complex. Links are provided to interactive tutorials and tests that I have developed to help students with these topics (see http://www.csu.edu.au/herbarium/).

At the "Select a Flower" page, students select one of the 12 flowers (Figure 3). They progress to a page where, in the upper section, four to eight images of the flower are presented, showing different angles and dissections (Figure 4). At this stage the images are mostly unlabeled, but in a very small number of cases some information is supplied that cannot be ascertained from the images but is needed to construct the floral formula. Below the image window is the "backbone" of the floral formula (i.e., K C A G: calyx, corolla, androecium, and gynoecium, respectively), along with 13 drop-down menus (Figure 4). After assessing the images, the student uses the drop-down menus to select floral symmetry, ovary position, numbers of parts in the various whorls, and fusion within or between whorls. The 13 menus allow all the major aspects of a flower to be recorded, although some more technical aspects (e.g., presence of staminodes, short and long stamens) that are found in some floral formulae cannot be recorded. The student progressively compiles the formula and submits it when complete. The submitted formula then appears above the "official" version, and any discrepancies are indicated by the presence of blue arrows that show which features should be reexamined (Figure 5). The images now have text boxes and/or labels to assist in the reexamination (Figure 5).

In the Classroom

At Charles Sturt University, first-year on-campus botany students (usually enrolled in applied fields such as agriculture and horticulture) receive a

Table 1. Genera used in the Virtual Floral Formula, with their family, order, and floral formula. Alternative family names are given where appropriate.

	Genus	Family	Order	Floral Formula
1	*Paulownia*	Bignoniaceae, Paulowniaceae	Lamiales	↑ K(5) C(5) A4 G(2)
2	*Hymenosporum*	Pittosporaceae	Apiales	* K 5 C 5 A5 G(2)
3	*Cotyledon*	Crassulaceae	Saxifragales	* K(5) C(5) A10 G5
4	*Hebe*	Scrophulariaceae, Plantaginaceae	Lamiales	↑ K(4) C(4) A2 G(2)
5	*Prunus*	Rosaceae, Amygdalaceae	Rosales	* K5 C5 A>10 G1
6	*Hypericum*	Clusiaceae, Hypericaceae	Malpighiales	* K5 C5 A>10 G(3)
7	*Kunzea*	Myrtaceae	Myrtales	* K5 C5 A>10 G(5̄)
8	*Primula*	Primulaceae	Ericales	* K(5) C(5) A5 G1
9	*Citrus*	Rutaceae	Sapindales	* K(5) C5 A>10 G(10)
10	*Eremophila*	Myoporaceae, Scrophulariaceae	Lamiales	↑ K5 C(5) A4 G(2)
11	*Nicotiana*	Solanaceae	Solanales	* K(5) C(5) A5 G(2)
12	*Gossypium*	Malvaceae	Malvales	* K(5) C5 A(>10) G(4)

Figure 2. The home page for the Virtual Floral Formula, showing the remarkable differences in the morphology of the flowers and inflorescences of some species of Australian Proteaceae, although they all share a very similar floral formula.

Figure 3. The "Select a Flower" page, showing the 12 specimens available for investigation.

single 2-hour practical session on floral structure, in which they investigate the structure of five to eight flowers. They are tested on the topic in a practical examination several weeks later. The Virtual Floral Formula allows them to review this material in the days immediately after the practical session and in the period just before the exam. A large proportion of the botany students are enrolled by distance education. These students attend an intensive 4-day residential school, where they study the same material covered by the full-time students in their weekly sessions. The ability to preview these practical materials before coming to the residential school has considerable advantages, as the students are already familiar with the topic and can use their time on campus more productively. Our botany practical sessions are held in the fall, a time when the variety of flowers suitable for dissection is limited; thus, with the Virtual Floral Formula, students can examine flowers they would not otherwise see. Additionally, the application provides an exemplar to students of the correct way to view and dissect a flower to observe all the main features.

I have photographed dissection sequences for several species other than those shown in the Virtual Floral Formula. I show these as occasional PowerPoint presentations in lectures and ask the students to write down the floral formula. The students then work together in small groups to arrive at a consensus regarding the correct answer. In discussing and debating their interpretation of the flower structure, they become

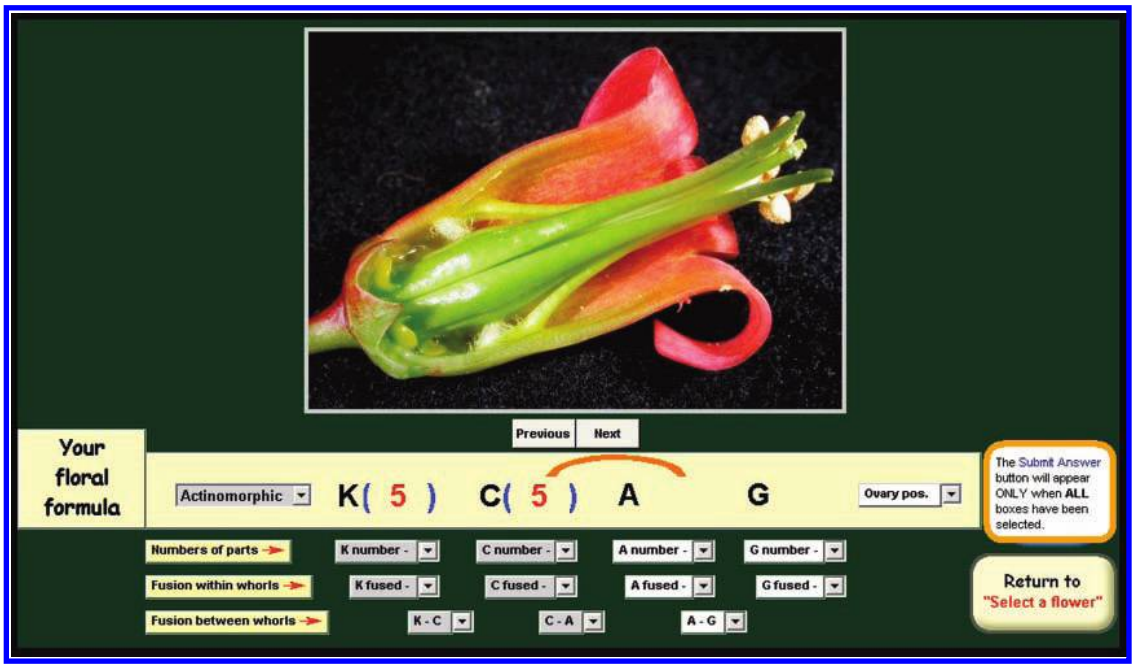

Figure 4. Specimen number 3, showing one of its eight available images. The floral formula has been partially completed, with 7 of the 13 features nominated (as indicated by the gray pattern on some of the drop-down menus).

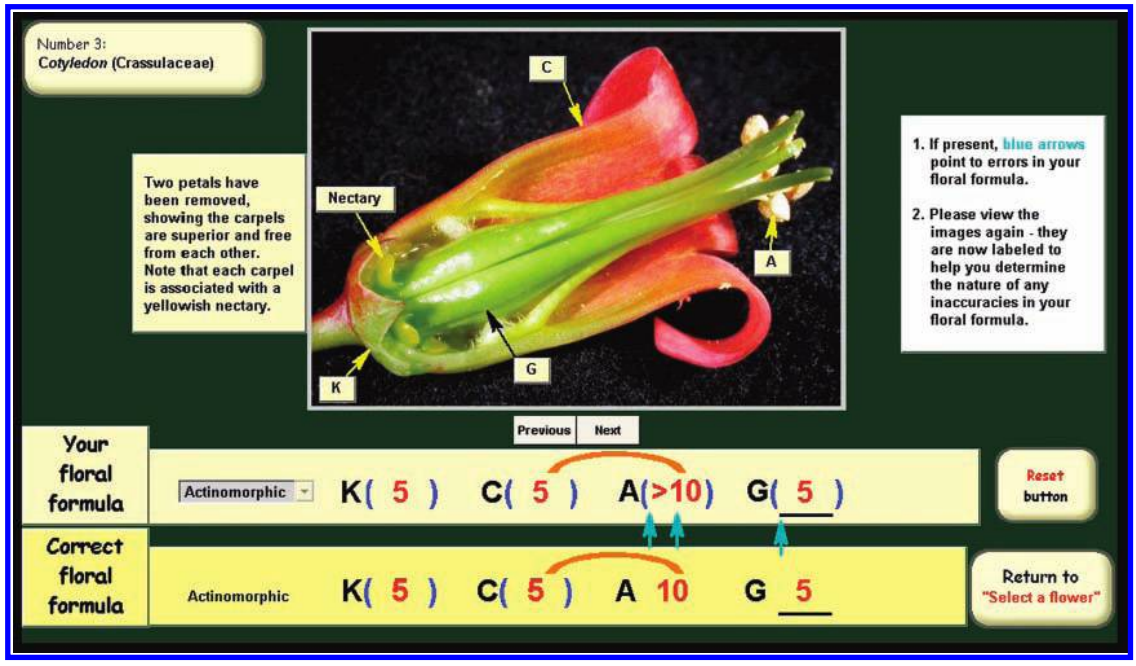

Figure 5. The partially completed answer shown in Figure 4 has been finished and submitted: the genus and family names are now available, and the image is labeled and annotated. The three blue arrows indicate that the number and connation of the stamens should be reexamined, as should the connation of the carpels.

more confident in their observations and use of the terminology. The combination of a practical session, the Virtual Floral Formula, and the PowerPoint presentations ensures that the students' knowledge of flower structure and function is continually refreshed and strengthened.

Floral formulae are also a good way to test students' knowledge of floral structure and terminology. In theory exams, as opposed to practical exams, I will often either provide a written description of a flower and ask students to write the appropriate floral formula or, more frequently, provide a floral formula and ask the students to describe the flower. In a higher-level taxonomy subject, I give students a list of several real or hypothetical floral formulae, along with some additional morphological features, and provide keys to family level from different published Floras. The students are then required to key out the floral formulae to family level. This is an excellent test of a student's ability to conceptualize the information in a floral formula and then apply it to the differently worded couplets found in different keys.

It is difficult to quantify the effectiveness of the Virtual Floral Formula in a way that is equitable and meaningful. Nevertheless, students' comments indicate that they appreciate the interactive learning environment, the way the application provides feedback regarding mistakes, that they can take their time and repeat the application at various times during the session, and the progressive improvements in their skills.

○ Other Resources

As best as I can tell, there is nothing available for plants that is even remotely similar to the Virtual Floral Formula, either on the Web or commercially. Some other relevant resources are as follows.

A virtual flower dissection for younger students (suggested ages 9–10) is available on the BBC's school pages at http://www.bbc.co.uk/schools/scienceclips/ages/9_10/life_cycles.shtml.

Digital Daisy (McIntosh & Richter, 2007) presents ideas on the use of digital microscopes to enhance the investigation of floral morphology and the construction of floral formulae.

The Digital Flowers Web site, hosted at the University of Illinois (http://www.life.illinois.edu/help/digitalflowers/), contains a wealth of information regarding families of flowering plants. The site has detailed information on 35 angiosperm families, usually with between 10 and 50 images related to the family. The first image is always the floral formula for the family, which is supported by various close-up images of flowers and dissections of flowers. Usually there are insufficient images to check all aspects of the floral structure, which is understandable, as this is not the purpose of the site. For example, there are relatively few cross sections of the ovary to check carpel number. Flowers of seven species are also presented to show various aspects of floral structure and floral formula construction. Each species is illustrated by one to three images. Again, these images show the main, but not all, features of the flower's structure.

○ Summary

Investigating floral structure is an important part of the biology curriculum, but students often examine only a very limited diversity of species and have limited opportunities to revise this material before examinations. The Virtual Floral Formula application overcomes many of these limitations by allowing students to progressively assemble a floral formula based on their interpretation of a series of high-quality dissection images. The Virtual Floral Formula should be a useful learning tool for almost all botany students, especially those in their first year of university study.

○ Acknowledgments

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