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Design and Construction of Two Large-Scale Botanical Models: A Sunflower Capitulum and a Grass Spikelet

Nisa Blackmon, Illinois Wesleyan University

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DESIGN AND CONSTRUCTION OF TWO LARGE-SCALE BOTANICAL MODELS:
A SUNFLOWER CAPITULUM AND A GRASS SPIKELET

Submitted to
Graduate Advisory Committee
Dr. Ronald J. Tyrl
Dr. Margaret S. Ewing
Prof. David M. Roberts

by Nisa R. Blackmon
Master's Candidate
Natural and Applied Sciences
Oklahoma State University
Stillwater, Oklahoma

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All photographs and illustrations by the author unless otherwise specified. Cover illustrations from Bremer, 1994 (sunflower), and Benson, 1959 (grass spikelet).

Correspondence is welcome and any inquiries may be addressed to the author at:

    Nisa R. Blackmon
    Department of Math & Science
    Brenau University
    One Centennial Circle
    Gainesville, GA 30501
    Wk: (770) 534-6280
I. Introduction

During the years that I worked on the models, my thoughts about the project changed significantly. I began with the simple goal of having my work culminate in two scientifically accurate, visually pleasing, durable models, which would be practical teaching tools. I envisioned a neat and tidy application of my skills as an artisan to the physical representation of scientific data. I should have known that very little about art or science is ever so easily encompassed.

In my own artwork, I often make use of botanical forms and phenomena as a formal addition to the work, or as a means of analogizing. In this role, I am the artist using science to enhance the art. As the designs for the models began to unfold, both on paper and during construction, I found myself reversing that role, becoming the scientist needing art to enhance the science. While I wanted the models to be as scientifically accurate as possible, I did not want them to become the placid, plastic blobs of my early classroom experiences (which, ironically, are sometimes far from accurate). I knew that the appearance of the models would be important, but in a different sense, I also wanted them to embody some of the sense of mystery and wonder that I perceive in the botanical world, and that it brings to my artwork. To express that desire in terms of aesthetics, I wanted the models to become not only mimetic - true representations of the physical world - but also expressionistic, conveying to the user some of the importance that the beauty of natural forms has for me.

However, it is not really possible to communicate the essence of how to achieve the aesthetic goals of this project in an instructional document such as this. One can only focus on the mechanics of the procedures; the sensitivity must be left to the individual artisan.
II. Objectives

The objectives of this project were to design, construct, and document construction of two large-scale, botanical models: the inflorescence known as a capitulum, which is unique to the sunflower family, and the inflorescence known as a spikelet, which is characteristic of the grass family. This endeavor utilized the knowledge and techniques learned in my studies of plants and in the various studio art disciplines. The models will be used in courses offered by the Department of Botany at Oklahoma State University.

This report details the approach and techniques used throughout the project, including measurement of each inflorescence's characteristics, photographic documentation of capitular morphology, tools and materials used, and design and construction procedures employed. Practical information of this nature is limited; I hope that this report will prove valuable to students attempting such undertakings in the future.

This project is both specific and general in its goals: to take precise measurements of morphological characteristics and represent those as accurately as possible in the models, which, at the same time, must be instructionally functional, three-dimensional, balanced, and durable. Thus, I found it necessary at times to alter and extrapolate from those measurements to facilitate construction and future use of the models. The requirements of teaching guided my decisions when conflicts arose. As a result, the features of the models emphasize the most common forms and arrangement of morphological structures in representative species of the grass and sunflower families. Some characteristics that vary among the members of the taxa have been simplified or omitted to prevent confusion. Some of the more delicate morphological features have been reduced or omitted entirely to facilitate handling of the models and to increase their durability. Emphasis
was placed on the use of materials that are lightweight, durable, inexpensive, and easy to obtain. With a few exceptions, the equipment and procedures used are available to most students of the sciences and studio arts, they can be adapted, or substitutions can be found to fit specific needs.

III. Species Descriptions and the Nature of the Models

A. *Helianthus annuus* (annual sunflower) is an archtypical member of the Family Asteraceae (Figure 1). It is relatively large in size and geographically widespread. The sunflower model represents a capitulum inflorescence, typical of the entire Asteraceae, with two different types of sessile, reduced flowers (florets) crowded together in concentric whorls on a convex receptacle, or disk. The model is wedge-shaped, representing one quarter of a capitulum, and shows the transverse, radial and tangential surfaces one might encounter during dissection (Figures 2.1, 2.2, Plate A). For clarity of reference in the rest of the text and in the illustrations and plates, I have assigned a letter (A through G, Figure 3.) to each side or surface of the sunflower model. Side E bears a two-dimensional illustration of a longitudinal section through the capitulum. The drawing is secured under a thin piece of plexiglass, cut to match the contours of the model. The other side of the wedge, Side B, offers a three-dimensional representation of the disk florets and ray florets along a radius of the capitulum. Some of the disk florets are removed to reveal Surface C, the bare receptacle (Plate C).

The disk florets are arranged in concentric whorls on the receptacle and illustrate the biomathematical relationship known as Fibenachi’s number series: the number of florets in a given whorl is the total of the florets in the two whorls immediately inside of it. Based on my sample counts of several heads, there are typically several hundred disk florets in just one quarter
of a capitulum (Figure 4)! This aspect of sunflower morphology, while interesting, was a prime candidate for modification because of the realities of floret construction. Ultimately, the model was designed so that it was largely a solid block of wood, the top of which, Side A, would be covered by individual pieces representing the apices of the disk corollas, the anther tubes, the style branches and the tops of the receptacular bracts. The florets found on Side B, the three-dimensional face of the model, would extend up over the top edge of the block onto Side A, providing a realistic transition between the side view and the top view. The floret tops found along the edge of Side A adjacent to Side E would represent a longitudinal cross-section and would be painted to blend in with the illustration.

The different nature of the ray and disk florets is emphasized on the model. The disk florets, found in the inner whorls, have an inferior ovary which matures into an achene, a pappus of two broad scales, and a five-lobed corolla with a bulbous area just above the ovary (Plate J). This area is thought to accommodate the coiled stamen filaments prior to the opening of the corolla lobes. The disk florets of *H. annuus* are sexually perfect, with a fertile pistile and five stamens. The anthers are united into a tube around the style. Stigmatic regions are located along the abaxial surfaces and distal ends of the two style branches. On the model, one complete disk floret, located in the cleared area of the receptacle (Surface C), is removable for study. The three-dimensional disk florets along Side B of the model are constructed as a series of longitudinal halves and show the progress of floret maturation, from the outer, older whorls of florets toward the inner, younger ones. This directional maturation is also shown on Surface A of the model, which is covered by individual apical sections of the disk florets and chaff; these have been constructed to show progressive stages of floret development (corolla opening, stamen tube exsertion, and style branch
Each disk floret is subtended by a large membranous scale, known as a pale or receptacular bract. Collectively, these bracts are known as chaff. They clasp the individual florets and have three to five apical lobes (Plate F). The central lobes extend above the corollas of the younger disk florets, but are eventually surpassed by the growing florets. Each receptacular bract is attached to the receptacle at the base of the floret. On the model, the removable disk floret has its own attendant bract, which is also removable (Plate J). The rest of the chaff structures on the model are, like the florets they subtend, partial in nature and permanently attached.

The ray florets, found at the perimeter of the receptacle, also have an inferior ovary and a pappus of two scales. The five petals of the corolla are fused to form a short tube at the base and a broad blade at the apex. They are either pistillate or neuter, in any case having no stamens, and therefore no bulbous area on the corolla tube just above the ovary. They also have no subtending chaff.

The model bears five ray florets; one found at the edge of the cleared receptacle area is completely removable (Plate I). It also bears a branched style that can be removed if desired. The other four florets have corollas that are removable for storage, but their ovaries remain permanently attached to the receptacle. When in place, the corollas fit over pegs arising from the ovaries and are supported by brackets attached to the back of the wooden block. When not in use, it is intended that the whole ray floret and the other corollas will be stored in an accompanying wooden box to protect them and to allow a cover to be placed over the rest of the model.

The surface of the receptacle is dimpled; a floret is seated in each depression. This surface will be shown on the three dimensional side of the model, representing an area where all of the separation) from the center of the capitulum to the perimeter (Plates E, F, G).
The florets are subtended by a series of larger green bracts called phyllaries, or involucral bracts, arising from the sides of the receptacle (Figure 2.2, Plate C). Collectively they are referred to as the involucre. These phyllaries are arranged in 4-5 overlapping series. They differ in size and shape, ranging from short, broad ones at the base of the receptacle, to long, slender ones adjacent to the ray florets. Awns that normally occur in varying sizes in the ranks of the involucre have been shortened or thickened on the model to decrease the chance of breakage (Plate H).

B. Poa pratensis (Kentucky bluegrass) is the type species of the Family Poaceae, or the grass family (see Figure 5). Grass inflorescences are known as spikelets, and consist of reduced flowers and bracts borne along a central axis (Figure 6). A pair of large bracts, called glumes, are found at the base of the spikelet, indicating where the spikelet begins. On the model, the glumes are removable from the axis. The rachilla is the central axis of each spikelet and its segments between adjacent florets are called rachilla joints. The individual florets are attached to the rachilla in two vertical ranks and consist of a reduced flower and two subtending bracts. The larger, abaxial (away from the rachilla) bract is the lemma and the smaller, adaxial (closer to the rachilla) bract is the palea (Figure 7). On the model, both lemma and palea are removable from the rachilla (Plate M).

A grass flower is composed of the lodicules, stamens and pistil (Figure 6). The lodicules are two small fleshy structures with membranous appendages. They are found inside the lemma and palea at the base of the ovary. Modified sepals, they are thought to aid in opening the floret at maturity. Three stamens are present, each with a slender filament. Two united pollen sacs

disk florets but one have been removed (Surface C, Figure 3).
make up the anther; as the floret matures, they begin splitting apically to release the pollen. On
the model, the anthers are constructed to show apical pores open to various degrees with remnants
of pollen grains inside (Plate N). The pistil of *P. pratensis* comprises a superior ovary bearing
two style branches with bushy or spiky stigmas. The fruit is a caryopsis or grain.

*Poa* spikelets are compressed laterally; the direction of compression is along the margins
of the lemmas and paleas. They are flattened so that the midnerves of the lemmas and glumes are
found along the outer edge of the spikelet (Figure 7), which appears to lie flat on its side. This
is a common feature of the pooid grass tribes and is represented in the model (Plate K).

Each model is permanently mounted on an oak base and has its own protective plexiglass
cover. Each morphological structure on the models is marked with a letter, and a corresponding
legend has been attached to each base in such a manner as to be removable for review or testing
purposes as needed. The sunflower model is accompanied by a wooden box for storage of the
removable ray florets.
IV. Education and Training

In order to conduct such a project, it is very important that one have completed not only the appropriate botany courses, but also basic studio art courses. The following have been invaluable to me: BOTANY: General Botany, Oklahoma Field Botany, Plant Taxonomy, and Agrostology. These courses provided all the botanical information needed to investigate and design the models. Plant Physiology and Mycology also were important in my botanical training; had time allowed, I would like to have taken Plant Anatomy, Plant Diversity, and Aquatic Botany/Limnology as well.

STUDIO ART: Design I, Drawing I, 3-Dimensional Design, Sculpture I, Jewelry and Metals I and II, and Ceramics I (handbuilding). I did not build botanical models in the art courses, but I did learn how to use tools that were essential to this project and how to photograph my work. I also became acquainted with a host of concepts and techniques involved in building a three-dimensional object. These courses also introduced me to ways of thinking and problem-solving that were essential when I was experimenting with new designs, new materials, and methods of construction. Given time, one or two semesters of Illustration would have been a valuable addition to this program, as would have Design II (color theory) and Drawing II.

Studio courses should also be taken for one’s safety. In all the three-dimensional art courses, I learned to use hand-held and stationary industrial power tools, which later made building the models much easier, but which can be quite dangerous if one is not experienced and comfortable with using them. For this reason, this manual is written from the standpoint of one who has had all of the courses listed above. It would be very unwise to attempt some of the procedures that I have used without this training.
V. Measurements of Living Specimens

Measurements were made using a dissecting microscope with an ocular micrometer, at 10x or 20x magnification. I also used a clear plastic metric ruler, simple dissecting tools, and a high-intensity illuminator. Each set of sunflower characteristics was measured on 25 different capitula of *H. annuus* gathered in early October of 1993. Each set of grass characteristics was measured on one spikelet of 25 different stalks of *Poa pratensis* gathered in the spring of 1993. I found it unnecessary to measure more specimens because of the uniformity in size of the characters among plants of the same age.

Mean values for the characters measured are given in Tables 1 and 2.

VI. Color samples

As the measurements were made of the fresh specimens, color samples were created to accurately reflect the colors exhibited by the live plants. Berol Prismacolor pencils worked very well for this because it was easy to combine and record the colors while observing the specimen through the microscope. I waited until later in the project to mix the actual colors of paint that I would be using, but it would have been better if I had mixed samples to match the fresh plants and recorded the formulas for later use. Dried and pressed specimens were useful for looking at patterns and markings, but were not accurate for matching colors.
Table 1: **SUNFLOWER MEASUREMENTS** (cm)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>capitulum height: from top of disc florets to bottom of involucre</td>
<td>1.900</td>
</tr>
<tr>
<td>capitulum width: 'petal' tip to 'petal' tip across center of disk</td>
<td>9.425</td>
</tr>
<tr>
<td>stem (peduncle) width at approx 1/4&quot; from base of involucre</td>
<td>0.325</td>
</tr>
<tr>
<td><strong>phyllary length</strong> (w/o bristle)</td>
<td>1.308</td>
</tr>
<tr>
<td><strong>phyllary width</strong> (at widest point)</td>
<td>0.687</td>
</tr>
<tr>
<td>phyllary overlap (at base)</td>
<td>0.200</td>
</tr>
<tr>
<td>number of phyllary rows in involucre</td>
<td>4.0</td>
</tr>
<tr>
<td>number of phyllaries per row (4 different rows)</td>
<td>6 - 10</td>
</tr>
<tr>
<td>involucre height: from base to tip of last row of phyllaries</td>
<td>0.825</td>
</tr>
<tr>
<td>involucre width: bract tip to bract tip across center of disk</td>
<td>4.750</td>
</tr>
<tr>
<td>receptacle height: top center of receptacle to just above the bottom involucre row</td>
<td>0.338</td>
</tr>
<tr>
<td>receptacle width</td>
<td>1.775</td>
</tr>
<tr>
<td>disk floret total length - young: corolla tube closed</td>
<td>0.960</td>
</tr>
<tr>
<td>disk floret total length - mid-development: anther ring extended, style branches not showing yet</td>
<td>1.30</td>
</tr>
<tr>
<td>disk floret total length - mature: style branches fully extended and open</td>
<td>1.438</td>
</tr>
<tr>
<td>disk corolla tube length (excluding length of lobe)</td>
<td>0.780</td>
</tr>
<tr>
<td>disk corolla lobe length</td>
<td>0.128</td>
</tr>
<tr>
<td>disk achene length</td>
<td>0.373</td>
</tr>
<tr>
<td>disk achene width</td>
<td>0.150</td>
</tr>
<tr>
<td>disk pappus length</td>
<td>0.288</td>
</tr>
<tr>
<td>disk style length: to point of branching</td>
<td>0.80</td>
</tr>
<tr>
<td>disk style width</td>
<td>0.034</td>
</tr>
<tr>
<td>disk style branch length: from point of branching</td>
<td>0.318</td>
</tr>
<tr>
<td>disk style branch width: across stigmatic surface widest point</td>
<td>0.073</td>
</tr>
<tr>
<td>Measurement</td>
<td>Value</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>disk stamen tube length</td>
<td>0.475</td>
</tr>
<tr>
<td>disk stamen tube width</td>
<td>0.098</td>
</tr>
<tr>
<td>disk filament length</td>
<td>0.483</td>
</tr>
<tr>
<td>disk anther base length</td>
<td>0.050</td>
</tr>
<tr>
<td>disk anther width (individual)</td>
<td>0.050</td>
</tr>
<tr>
<td>disk anther tip length</td>
<td>0.075</td>
</tr>
<tr>
<td>receptacular bract length (chaff)</td>
<td>1.125</td>
</tr>
<tr>
<td>receptacular bract width</td>
<td>0.323</td>
</tr>
<tr>
<td>ray floret total length</td>
<td>4.350</td>
</tr>
<tr>
<td>ray corolla length: from top of constriction</td>
<td>3.913</td>
</tr>
<tr>
<td>ray corolla width: at widest point</td>
<td>1.167</td>
</tr>
<tr>
<td>ray corolla nerve number: major/minor</td>
<td>2/18</td>
</tr>
<tr>
<td>ray achene length</td>
<td>0.410</td>
</tr>
<tr>
<td>ray achene width</td>
<td>0.150</td>
</tr>
<tr>
<td>ray pappus length</td>
<td>0.223</td>
</tr>
<tr>
<td>ray corolla constriction above achene</td>
<td>0.280</td>
</tr>
<tr>
<td>receptacular bract length to first sinus</td>
<td>0.655</td>
</tr>
<tr>
<td>receptacular bract small lobe length</td>
<td>0.138</td>
</tr>
<tr>
<td>number of florets across disk cross section</td>
<td>15</td>
</tr>
<tr>
<td>disk floret length - young (floret) achene length</td>
<td>0.180</td>
</tr>
<tr>
<td>disk floret - young (floret) achene width</td>
<td>0.130</td>
</tr>
</tbody>
</table>

** These measurements represent the average size and shape of the phyllaries in the first row adjacent to the peduncle. During construction, however, I realized I had not accounted for the other distinctly different shapes of phyllaries found in the next three rows. Lacking measurements for each specific shape, I extrapolated from those I did have, and made visual estimates of size relative to the the phyllaries in the first row.
Table 2: GRASS MEASUREMENTS (cm)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>lemma length</td>
<td>0.290</td>
</tr>
<tr>
<td>lemma width</td>
<td>0.065</td>
</tr>
<tr>
<td>lemma depth: measured from lemma midnerve to margin</td>
<td>0.050</td>
</tr>
<tr>
<td>palea length</td>
<td>0.245</td>
</tr>
<tr>
<td>palea width</td>
<td>0.035</td>
</tr>
<tr>
<td>stigma length</td>
<td>0.103</td>
</tr>
<tr>
<td>stigma width: at widest point of stigmatic surface</td>
<td>0.020</td>
</tr>
<tr>
<td>style length</td>
<td>0.010</td>
</tr>
<tr>
<td>style width</td>
<td>0.005</td>
</tr>
<tr>
<td>anther length</td>
<td>0.120</td>
</tr>
<tr>
<td>anther width</td>
<td>0.023</td>
</tr>
<tr>
<td>filament length</td>
<td>0.255</td>
</tr>
<tr>
<td>ovary height</td>
<td>0.033</td>
</tr>
<tr>
<td>ovary width</td>
<td>0.018</td>
</tr>
<tr>
<td>lodicule length</td>
<td>0.030</td>
</tr>
<tr>
<td>lodicule width</td>
<td>0.015</td>
</tr>
<tr>
<td>rachilla joint length</td>
<td>0.075</td>
</tr>
<tr>
<td>apical pore length (in anthers)</td>
<td>0.044</td>
</tr>
<tr>
<td>length of area where dehisced anther lobes are joined</td>
<td>0.050</td>
</tr>
<tr>
<td>lemma hair length</td>
<td>0.170</td>
</tr>
</tbody>
</table>
VII. Photographic Methods

Ideally, all of the small plant structures would have been photographed with a camera attached to a dissecting microscope. I found that, even when photographed with a macro lens, some images did not contain enough detail to be useful references during construction. A set of close-up lenses (1x, 2x and 4x) would have enabled me to obtain some more detailed images, but I did not have a set at that time. Even so, I was able to get many good slides of the sunflower’s morphology by using a larger, domesticated form of *H. annuus*, donated by a local florist. At the time, wild annual sunflowers were not flowering. There were, however, several morphological differences between the domesticated and the wild forms that had to be considered. Thus, the slides were useful for general reference and for later presentations on the project, but were of limited use for detailed reference during construction of the model.

The spikelets of *Poa pratensis* were too small to photograph with a macro lens. I borrowed existing slides for my presentation and kept dessicated specimens in view on the stage of a dissecting scope while I designed and constructed the various components of the model. Grasses dry very well when hung upside down in a cool place, and the spikelets retain their characteristics well enough for later reference.

A. Photographic Equipment used:

- Minolta X-370N 35mm camera body with automatic and manual setting capabilities
- 28-70, 55mm zoom lens
- 28-200, 67mm macro/zoom lens
- photographic copy/light stand, with four 3500 K tungsten bulbs
- plate glass
- adjustable tripod
- two light stands with 3500 K tungsten bulbs, 500 watts
- two white diffuser umbrellas
photographic background paper
matte Canson paper: black, white, dark green and gray
neutral gray card
Ektachrome 64T (tungsten) slide film, Kodachrome 64 ASA or Ektachrome 100
ASA slide film, 100 or 200 ASA color print film if desired
55mm Fluorescent/Daylight (FLD) filter
55mm 80-A tungsten filter

B. Procedure

The copy stand was used to photograph the dissected sunflower organs, as well as diagrams and illustrations for later presentations. I had access via the Botany Department to one which provided 4 tungsten bulbs, as well as a transformer with different light level settings. The Jewelry and Metals Class allowed me to use a tripod, diffuser umbrellas and two 3500 K tungsten bulbs on light stands to photograph the finished models. During construction, I used a tripod and fluorescent or incandescent (tungsten) lights, with a Canson paper background, to photograph the different model parts and phases of construction.

When using the tungsten slide film, I eliminated all other light sources except for the tungsten bulbs. When fluorescent lighting was used, I attached an FLD filter to the camera lens to reduce the green tint, which would otherwise be very noticeable. When daylight film was used under tungsten (incandescent) lighting, I used an 80-A blue filter to reduce the yellow tint. Using the tungsten slide film under tungsten lights produced the truest color. All films were kept in a refrigerator, then taken out 30 minutes before use and allowed to come to room temperature.

Exposure time and F-stops for each film were determined using a photo grey card. I selected the F-stop to give the greatest depth of focus (16 or 11). I found that with my automatic camera I did not have to bracket my shots with different shutter speeds; however, one should experiment with different methods depending on the camera.
Several different background papers - black, white, and grey -- were used for the photographs of dissected organs. For lighter subjects, I used darker paper, and vice versa, but avoided brightly colored papers. Using a white background resulted in the most vivid colors, while the best presentation slides were taken against a more neutral background.

Emphasis was placed on photographing those features of the sunflowers that were qualitatively subtle, such as contours of the ligules, or gradations of color in the chaff, phyllaries and disk corollas. The slides were also used in later presentations and for reference to general appearance and morphology.

When taking photographs of published illustrations on the copy stand, a sheet of non-glare plate glass was placed over the page to eliminate shadows and ensure evenness of focus.

VIII. Materials and Tools

A. Consumables

WOOD: assorted sizes of wooden dowels; basswood and pine blocks; plywood; wooden balls; laboratory applicator sticks (approx. 1/16" diam); oak boards or oak plywood
large solid pieces of styrofoam packing
lightweight 1½" copper flashing
white polymer clay
miniature PVC tubing (1/8" outside diameter)
Aluminum wire screening, 10 or 12 ga Aluminum wire,
20 ga aluminum sheet
1/4" diameter brass pipe
copper wire (16, 20, 22 gauges)
16 gauge steel piano wire
thin sheet brass or small commercial L-brackets
drywall putty compound
polyester/nylon organza fabric
clear nylon thread
lightweight cotton canvas, tightly woven
thin sheet cork
jute rope or twine
chenille pipecleaners
model railroad ballast gravel, light grey, medium
primers, paints, varnish, spray texture (Delta Ceramicoat brand acrylic paints and
 varnish are well suited for this use.)
carpenter's WoodBond glue, white craft glue, epoxy (if needed)
assorted screws, tacks or nails
file cards, manila folders, chipboard, etc.
emery boards, assorted grits of sandpaper
1/16" plexiglass (8x10 and 4x6 sheets), and 1/8" plexiglass
tracing paper
masking tape and drafting tape
small black rub-on letters

B. Handtools:
screwdrivers
wood chisels/gouges and assorted sculpting tools
wood carving mallet
wood files and rasps, sur-form tools, sand paper of assorted
 grits
small putty and/or palette knives
coping saw, hacksaw and crosscut saw
jeweler's saw and size 1 blades
L-square, rulers, measuring tape, circle and oval templates
Staedtler compass, rapidiograph pens
wire cutters, needle-nose pliers, round-nose and flat-nosed pliers
tin shears or heavy duty scissors, regular scissors
embroidery needle
hammer
paint brushes, stirring sticks, rag sponges, Q-tips
C-clamps, bench vise, pony clamp, bench pin or v-block
aluminum oven liner trays
staining rags

C. Power tools and appliances:
household oven or plant drying oven
power drill, assorted bits, wood bores, rotary files
flexible shaft or dremel tool, assorted drill bits and grinding bits
handheld belt sander or rotating sander
industrial bandsaw and beltsander
circular saw
floor-mounted drill press
table saw
IX. Construction Procedures

A. Scale of models

Models were constructed at an approximate scale of 1:10 for the capitulum of *Helianthus* and 1:100 for the *Poa* spikelet. Occasional adjustments in proportions were necessary to facilitate construction.

B. Templates and prototypes

After all measurements were made, I constructed patterns or templates from file cards, manila cardstock, chipboard, or styrofoam for as many structures as I could. This enabled me to visualize how parts would go together and how I would need to manipulate the materials. The templates also were used later when cutting the materials - cloth, clay, screenwire, etc. - for the model parts. Assembling these patterns into three-dimensional prototype structures was also helpful in developing the construction processes. I experimented with many different materials and methods of construction. What I have recorded here is only one approach; there might be others that work better or applications that could be used for models of other botanical structures.

Testing the materials was important at this early stage. Every combination of materials needed to be examined, such as the durability of the polymer clay over the screenwire, the strength of clay glued to wood or to itself, or the adherance of acrylic paint to the clay. I experimented beforehand with every permutation of materials and tools that would have to interact during construction. There were still a few surprises later, but not many.
C. Construction of the Sunflower Capitulum

1. Receptacle block and stem. A prototype was made for this structure by gluing pieces of styrofoam together into a large block, then carving out the desired shape. The 1"-thick blue insulation foam used in commercial construction has a very fine grain and is easily carved. This helped tremendously when I began to do the major cutting and carving of the wooden block. Figure 8 illustrates the major steps of the carving process.

   a. Carving the receptacle required a basswood board, 4" thick, about 9" wide, and 18-20 inches long. I had both sides planed by a professional, cut two wedges according to diagrams, laminated them together, and sanded the faces that were not to be carved away.

   b. The block was trimmed to its basic shape using a bandsaw, then chiseled, sawed and carved, as needed to obtain the final shape. I added details such as the dimpled receptacle surface and drilled the hole for the peduncle (Figures 8, 9.1), sanded and filled or smoothed with drywall putty as needed.

Later in the construction process, I realized that the ledge on the back side of the block where the ray florets were to be pegged was not wide enough. I built an extension piece of polymer clay and fashioned a supporting bracket from 20 gauge aluminum sheet to hold it, and screwed both parts into the underside of the receptacle block (Figures 9.1, 9.2, Plate B). It was quite effective. Drywall putty was used to hide all the seams between the extension and the block, then sanded smooth when dry.

Peg holes for the detachable disk floret and the five ray florets were drilled
into the receptacle extension after the ray floret ovaries and pegs were constructed.

c. I constructed the sunflower peduncle from a smaller block of basswood and drilled two 1/4" peg holes in the top and two holes for screws in the bottom (Figure 9.1).

d. Two corresponding 1/4" peg holes were drilled in the receptacle block peduncle hole.

e. 1/4" dowel pegs were cut to fit and the peduncle was glued in place.

f. The joint area was smoothed with putty.

g. Screw holes were drilled and countersunk in a temporary plywood base board. The model was then attached to the board, temporarily with only one screw, so that removal and reattachment of the model during construction would be easier.

2. Fabrication of the ovaries for the series of longitudinal half-florets and for the detachable disk floret. These ovaries were all carved from basswood blocks. The ovaries from the half-floret series were made with one side flat, so that they could be attached directly against side B of the receptacle block (Figure 10, Plate B).

a. With a coping saw, I cut the rough shapes from thin slabs of basswood, then filed, carved and sanded to achieve the final shape.

b. 1/8" peg holes were drilled in the top and bottom of the ovary for the detachable disk floret (Figure 11).
3. Phyllary series. At this point, I began to roll out thin sheets of polymer clay, 1/8 - 1/16" thick, to cover all of the screenwire forms.

   a. Four size classes of phyllaries had been measured. I determined how many of each class were needed and marked their spacing on the receptacle.

   b. Screenwire forms were cut out using templates and heavy shears, and shaped to fit the curvature of the underside (Side G) of the receptacle block with the extension in place.

   c. 20 gauge copper wires were cut for midnerves on each of the three largest sizes of phyllaries; these also were shaped to the correct curvature.

   d. Both sides of each phyllary were covered with a layer of polymer clay, taking care not to trap any air between the layers or around the wire. The curvature against the receptacle block was checked again.

   e. Using the directions and temperature supplied by the manufacturer, the phyllaries were baked in a plant-drying oven. Baking took longer than the recommended time. Position and curvature of the phyllaries were rechecked after baking was completed.

   f. I marked the holes for screws needed to attach the phyllaries to the receptacle and drilled them in both structures.

   g. The phyllaries were sanded to a smooth surface, and any cracks or dents were filled with drywall putty and sanded smooth.

4. Construction of the ray florets. The five ray florets were made to be removable
for storage or study. Four of the florets were made to separate between the top of the ovary and the base of the corolla tube. The ovaries would remain permanently attached to Side F of the receptacle block as shown in Figure 12. The last floret was made to be detachable as an intact unit.

a. The ray floret ovaries were made from polymer clay and baked. A 1/4" hole was then drilled lengthwise through each ovary to facilitate pegging to the receptacle. There was some difficulty with the edges of the hole breaking as I was drilling. Five 1/4" dowel sections were cut long enough to extend about 3/4" past the bottom of the ovaries and approximately 2 1/2" above the top and then inserted. A small screw hole was drilled through four of the ovaries, from front to back, also passing through the wooden dowel. This allowed the permanently attached ovaries to be mounted by a screw to Side F of the receptacle block, as well as being pegged to Surface C, for extra support (Figure 12). Pilot holes always had to be drilled into the polymer clay parts before inserting screws into them, or the clay would split.

b. With dowels in place, repairs were made to the ovaries with drywall putty.

c. Five screenwire forms for the ray corollas were cut using templates, and were designed so that one end of the screenwire form could be rolled in from the sides to form the tubular portion of the corolla.

d. 16 gauge copper wires were used to provide support for the ray corollas and to represent the larger veins of the ligule. Two wires per floret were cut to the
appropriate length and the upper ends were notched. Both were sewn onto the abaxial side of the screenwire corolla with clear nylon thread (Figure 12). The wires stopped approximately 1/4" before the end of the corolla tube. On the detachable ray floret, they extended approximately 1/2" past the end of the screenwire tube (Figure 13).

e. The screenwire was shaped to reflect the actual curvatures of the corollas, using my slides of the domestic form of *H. annuus* as a reference.

f. The ligules were covered with polymer clay in two stages. First, a thin sheet of clay was applied to the abaxial side of the screenwire form and to the tubular area. Where possible, I covered the inside of the tube as well, leaving a cylindrical opening slightly larger than 1/4" in diameter (in order to fit down over the 1/4" peg). The corolla was then baked while lying on its edge (the margin of the corolla blade); otherwise, it flattened too much during baking. The adaxial side of the screen was then covered with clay, surface details such as venation were added, and the corolla baked again, lying on its edge. This two-stage process helped eliminate unsightly air-bubble problems that I had with earlier construction attempts.

g. The diameter and fit of the corolla tube were checked against the top of the ray floret ovaries. Adjustments were made by filing and sanding, or by adding more clay and re-baking. The top portions of the wooden pegs were trimmed so that, with the corolla in place, none of them extended past the area where the tube began to flare out (Figure 12). Two holes were drilled in the top of the ovary of
the detachable ray floret to accommodate the two wires extending from the end of its corolla tube. In addition, a 1/8" hole was carefully drilled in the top of the ovary peg for this floret to accommodate insertion of a style (Figure 13).

h. Spacing of the ray florets on the ledge around the back side of the receptacle was determined, arranging them so that the ray corollas could be easily attached and removed. 1/4" holes were drilled in the ledge extension to accommodate each ovary peg. As a result of having to extend the receptacle ledge, the florets were being pegged into the clay instead of the wood. I thought some extra reinforcement was needed for the detachable ray floret, which had no other means of support. The hole which would hold this floret was enlarged slightly and reinforced by inserting a matching length of 1/4" brass pipe into the peg hole. This was further reinforced of the pipe and extended laterally as far as the original wooden portion of the receptacle, where it was screwed in (Figure 14). The lower end of the peg for the removable floret was carved down slightly to fit inside the pipe.

d. Any nicks in the corollas were filled and sanded.

ej. The corolla and ovary/peg portions of the detachable ray floret were glued together, the corolla wires extending down into the achene, and the dowel peg going up into the corolla tube. When dry, the joint was puttyed and sanded to obtain a natural appearance.

k. For the four attached florets, extra support was needed for the removable corollas. Four u-shaped aluminum brackets were fashioned from 1/4"-wide strips
of 20 gauge aluminum sheet and shaped to fit the areas of each corolla where the tube began to broaden into the ligule (Figure 12). With the corollas in place over the ovary pegs, the brackets then were individually adjusted to fit around the corolla tubes. They would be attached by screws to Side F of the receptacle block and would not impede the removal or insertion of the corolla (Plate H). The sharp edges of the brackets were rounded, filed smooth and sanded. Screw holes were drilled in the end tabs and the brackets were lined with a thin strip of sheet cork.

1. At this time, all the ovary/peg structures, corollas, brackets, and the detachable ray floret were removed from the wooden block to await painting and assembly.

5. Construction of the detachable disk floret (Figure 11, Plate J). This structure represents a single mature disk floret and features a fully extended anther tube and style branches, reflexed corolla lobes, pappus scales, and its subtending receptacle bract. Construction of some of these parts will be detailed in later sections. The floret sits on a peg in Surface C of the receptacle, in one of the dimples, in a position that matches the other florets of its maturity level (with respect to the longitudinal floret series, and the floret parts on the top of the model).

a. The ovary for this floret was carved from basswood earlier in the construction process. 1/8" peg holes were drilled in the top and bottom. A corresponding hole was drilled in the receptacle, and a peg cut from 1/8" dowel.

b. To make the bulbous portion of the corolla tube, a 1/8" peg hole was
c. The portions of the corolla tube below and above the bulbous area were made from polymer clay. To facilitate making the upper portion, a shape that would be repeated elsewhere on the model, I made the first of two cookie cutters from a narrow strip of copper flashing. The cutter was shaped to the outline of a paper template I had constructed earlier while making a prototype of the floret. Once the corolla shape was cut from a thin sheet of clay, it was rolled around a freshly sanded 3/8" wooden dowel, and the edges slightly overlapped and pressed together. Any build-up of clay residue on the dowel would cause the next piece of clay to stick, hence the sanding prior to each use. After carefully removing the dowel, I compressed the tube wall just below the corolla lobes to expand the apical diameter, creating the flared upper opening, then reflexed the corolla lobes. This structure, and others like it, were baked upright, which was precarious at best. Some of the longer corolla tubes fell over during baking, causing great frustration, much cursing, and burned fingers. After the first baking attempts, I started making extras of all the small clay parts in case of similar mishaps. The short constricted region between the bulbous area of the corolla tube and the top of the ovary was made from a simple tube of polymer clay, cut to size with a jeweler’s saw after baking.

d. The ends of the clay tubes which fit against the wooden ball were beveled for a closer fit. The clay parts were filed and sanded as needed.

e. A small section of 3/8" dowel rod was cut, and a 1/8" hole drilled completely through a 3/4" wooden ball.
carefully through the center, forming a thick-walled wooden tube about 1/2" long.

f. The disk floret parts were pegged and glued together as shown in Figure 11, with a single 1/8" peg, anchored in the top of the ovary and passing through the small clay tube, the wooden ball and the fabricated wooden tube. A space was left above the top of the connecting peg in the wooden tube; this would later hold the base of the style. The long corolla tube was then slipped down over the wooden tube and glued in place. Thus the fabricated wooden tube was multi-purposed: it provided greater surface area for gluing the corolla tube, a receptor hole for the base of the style, and also an elevated ledge upon which to glue the anther tube, which was constructed separately. All the seams and joints of the floret were then puttied and sanded for a realistic appearance.

6. Construction of the series of nine longitudinal disk floret halves showing a range of maturation. This arrangement of florets does not represent the actual condition of a dissected surface. Instead, I chose to present them in a more orderly fashion, to show clearly the morphological changes in disk florets as they age, and the directional nature of this process (Plate C). This series is located on Side B of the model; the ovary bases rest on Surface C. The florets were constructed so that a longitudinal cross-section fits against the receptacle block to the point where Surface A begins. Above this point, the top of the floret appears whole, representing whatever stage of maturity it is in (Figure 10, Plates B, D). Anther tubes, style branches, pappus and chaff for these florets were constructed separately; descriptions will follow in later sections.
a. Ovary longitudinal halves were carved from basswood as described earlier in the project.

b. From polymer clay, I constructed the different stages of corolla tubes as whole structures instead of longitudinal halves; they would later be cut and shaped to fit against the edge of the wooden block. The corolla tubes of the three youngest florets, still tightly closed, were made from polymer clay with no wooden parts. Surface details were added; then the pieces were baked. Afterwards, a section of the piece was sawed away to allow it to fit over the juncture of Side B and Surface A (Figure 10, Plate B). For the more mature florets in the series, I combined the clay pieces with the halves of small wooden balls to represent the bulbous area of the corolla tubes (Figure 10). This was the case for florets four through nine, number nine being the most mature. When the florets reached stages where their corolla tubes were partially or fully opened, the tube parts were constructed in the same manner as for the detachable disk floret (via cookie cutter), then cut to fit after baking. The last five floret tubes were made in this manner. When all the segments of each floret had been cut to fit and sanded, they were glued together, but not yet glued to the receptacle. This was a very fragile stage, where I first discovered that the white craft glue did not adhere to the polymer clay as well as I’d hoped. I decided to “stick” with this adhesive, however, and adjusted my procedure. I glued the floret parts together in stages, letting each joint between two floret segments dry completely before attaching the next segment.
7. Construction of the floret tops: corolla tube apices. These pieces represent the top two or three millimeters on an actual disk floret corolla tube. As stated earlier, I abandoned an attempt to reproduce Fibenachi's number scheme and instead made as many floret tops as I could get to fit in the space. This resulted in approximately 60 floret tops, comprising fourteen concentric arcs (or one quarter of a whorl) showing the different stages of floret maturity (Figure 2.1, Plate D).

a. The youngest, most tightly closed floret tops were shaped from solid polymer clay, with indentations made to represent the seams of the corolla lobes. There were two growth stages made this way, one slightly taller (older) than the other. After baking, the bases were beveled to fit the curvature of the top of the wooden block (Surface A) and a 1/16" peg hole drilled in the center of each (Figure 15).

b. To construct the middle-aged and oldest floret tops, I made a second cookie cutter from copper flashing, identical to the first one, but shorter, ending approximately 3/8" below the sinuses of the lobes. The cut shapes were again rolled around a sanded 3/8" dowel rod and joined. The lobes of these corolla tops were then pushed together on the younger florets (Figure 15) or reflexed to various degrees to reflect floret maturity. I made several extras of each different stage. After baking, the corolla tops were sanded as needed and the bases carved to fit the curvature of the wooden block.

The star-shaped nature of the older corolla tops made it difficult to position them close together in their rows, and several small blank areas on the head were
noticeable. When I re-checked pressed specimens of *H. annuus*, I realized that the corolla lobes of even the oldest disk florets stay nearly upright, not curled all the way down as I'd made many of them. In a crowded capitulum, they simply do not have room to do so, except in the outermost whorls. I chose not to redo them, and, in the end, it did not detract from the representation of the subject or the appearance of the model.

c. When all corolla tops were complete, they were positioned on top of the block, numbered, and their positions marked by tracing a circle around them. A correspondingly numbered map was drawn on tracing paper.

8. Construction of the anther tubes. For every corolla top or floret in which the lobes were open enough to see inside, an anther tube was made. There were two types (Figure 15):

a. Closed anther tubes were made from solid polymer clay for the younger florets, as per the examples of live specimens. After baking, they were sanded, the basal ends carved to fit the surface of the block, and holes drilled in them for 1/16" pegs.

b. The anther tubes for older florets were made from a dense cardboard stock, sometimes called chipboard, commonly found as a backing on notepads. The pieces were cut, scored to represent the seams of the united anther sacs, rolled and glued closed. The pointed tops were filed with an emery board to soften and round the edges. Anther tubes for the florets on top of the wooden block were
made tall enough to extend out of the corollas, corresponding to the developmental stage of the floret (Plate G). Anther tubes for the florets in the longitudinal series were made in the same way. The anther tube for the detachable disk floret was made in the same fashion, but longer, because it was seated farther down inside the corolla tube (Figure 11). No filaments were made, as this part of the floret will never be exposed on the model.

9. Construction of the styles, style branches and stigmatic surfaces. The styles were made from 1/8" diameter white plastic pipe found in the model-building section of a local hobby store. It resembles miniature PVC pipe.

   a. Pieces of the pipe were cut to lengths somewhat longer than were actually needed, for ease of handling during construction. A longitudinal groove was sawed in one end of each piece to a length corresponding to the measurements of the lengths of the style branches. The separated halves were warmed over an alcohol lamp and curled into place one at a time. I referred to illustrations and pressed specimens to get the correct curvatures for different maturity levels. Again, extras were made of each kind.

   b. The adaxial edges of the style branches were sanded to smooth them, and the trough in each branch and the center hole were filled with a 3:1 mixture of drywall putty and white craft glue. When this dried, it was sanded and refilled, dried, and sanded smooth again.

   c. To create the pubescent areas on the abaxial sides of the style branches,
I cut jute rope fibers into 1/4" lengths, leaving them somewhat clumped together. With tweezers, I glued them to the branches, one tiny clump at a time, working backward from the tips of the branches. This was tedious and painstaking, and nearly drove me insane -- but it was well worth the effort in the end.

d. When completely dry, the fibers were trimmed and shaped. At this time, the styles were cut to the proper lengths.

10. Wooden block, revisited. Peg holes were now drilled in the top surface of the block, approximately 1/2" deep, in the following manner: A 1/16" peg hole was drilled in the center of the traced circle position for every floret-top that was either closed (made of solid clay) or which had a closed stamen tube in its center. A 1/8" peg hole was drilled for every floret-top position which had a style branch in the center. Remaining floret tops were to be glued in, not pegged.

11. Construction of the chaff, chaff apices and pappus scales. These structures were made from a lightweight, tightwoven cotton canvas. The fabric retained most of its flexibility even after painting and varnishing.

a. I estimated the amount of material I would need for all chaff and pappus pieces. The entire piece of fabric was painted with two coats of the base membrane color, letting the acrylic penetrate the material thoroughly.

b. Using previously prepared templates, I cut out all the pappus and chaff parts. The pappus scales for the ray florets were omitted because of the likelihood
that repeated removal and insertion of the ray floret corollas on the model would eventually knock the scales off. The chaffy bracts for the row of longitudinal disk florets were constructed as halves of normal, folded receptacular bracts, with gradations in size and lobe length representative of the ages of the florets. Pieces were also cut to represent the tops of the receptacular bract lobes which would extend up between each floret, and be attached to the top of the wooden block (Figure 15, Plate F). Details of color and pattern were painted on and each was finally given two coats of varnish.

c. For the complete receptacular bract subtending the removable disk floret, the painted material was folded along the midnerve, and a short piece of 1/16" dowel glued to its base (Figure 11), extending downward to make a short peg at the bottom (Plate J). A corresponding hole was drilled in the receptacle beside the floret peg. The peg in the receptacular bract was painted and varnished to blend with the bract’s color.

12. Painting and assembly. I painted as many of the individual parts at the same time as I could before putting them together. Nearly all the details for this model were painted, using sponging and dry-brush techniques. I used slides, photographs, and dried specimens to match colors and pattern details. Prismacolor pencils were also used for some detail work on the anther tubes. To label different structures, rub-on letters were applied after the final coat of paint, but before being varnished.

a. All phyllaries were given one base coat of primer, then sprayed with
Fleckstone (TM) spray-texture. When their surfaces were completely dry, two coats of the basic green color were applied. Details were painted on, using a sponge and dry-brushing, and rub-on letters were applied as needed. Two coats of acrylic varnish finished these structures.

b. Ray floret corollas and ovaries were given two coats of primer, then two coats of their respective colors. Detail work on these parts was not needed. The tops of the pegs extending out of the ray achenes were painted the same color as the corollas that would fit onto them. Rub-on letters were applied where needed, then two coats of varnish. The aluminum brackets that supported the corolla tops, along with their cork liners, were given two coats of primer, two coats of the corolla color, and two coats of varnish.

c. The florets of the longitudinal series were given two coats of primer and two coats of their appropriate base colors. The maroon coloration patterns at the tops of the corollas and other details were then applied by dry-brushing (Plate G). The backs of the floret halves, which would be attached to the wooden block, were left unpainted. The detachable disk floret was painted in the same manner. Rub-on legend letters were applied where needed, and two coats of varnish finished these pieces.

d. The disk corolla tops were given one coat of primer and one coat of their yellow base color. The maroon color patterns were applied by dry brushing, and these pieces were finished with two coats of varnish.

e. All anther tube segments were given one coat of primer, then two coats
of their deep brown color. Details were added in yellow ochre Prismacolor pencil, and two coats of varnish applied.

f. The style branches were given two coats of primer, except for the fiber-covered areas. Two coats of base color were then applied, again excluding the fiber-covered areas. Maroon coloration was painted and dry-brushed on the style branches (Plate G), then two coats of varnish were applied to the entire structure. The maroon paint was the only color applied to the fiber-covered areas because of the difficulty in getting paint into all the cracks and crevices of the fibers. I didn't want to have the white color of the tubing and primer showing underneath.

g. When all of the individually constructed parts were completely painted, the wooden block was textured and painted. Everything but the abaxial surface of the involucre (Side G), the peduncle, the bare receptacle area (Surface C) and the ledge around the receptacle perimeter was masked, and a layer of spray-texture applied. The different faces of the block were painted in two ways: (1) they were painted to accurately resemble the natural or dissected surfaces (Sides C, D, and G); or (2) they were painted the same colors as the structures fastened to them, so that the areas visible would have the same general background coloration. This second technique was used specifically on Surface A, where the disk corolla tops were located, Side F, and Side B, where the longitudinal series of florets was located. Side E, which would bear the illustration, was not painted except for a base coat of primer and colors around its edges to blend it with the other faces of the block. All surfaces of the block were then given two coats of varnish, except
h. When the block was completely dry, I attached all permanent parts in the following order and manner:

- the ray floret ovaries, with pegs inserted through them, were glued in their respective peg holes and screws inserted through the ovaries into the wooden block (Figure 12). The screw heads were then filled with putty, sanded smooth, repainted, and varnished. The aluminum brackets also were attached at this time, and their screws painted to match the general background.

- the phyllaries were attached with screws, one row at a time, beginning with the innermost row adjacent to the ray florets. As each row was attached, patched and painted before the next row was put in place. The bases of the first and last phyllary in each row were smoothed with putty until they graded gently into the abaxial curve of the block. This resulted in a more natural appearance on Sides D and E (Plate C) of the model. On the fourth and lowest row, a smooth transition was made with drywall putty from the base of each phyllary to the peduncle. The sinuses between each bract were filled and smoothed as well. This newly puttied area was then masked and spray textured. While still wet, the new texture was feathered into the old, resulting in a uniform surface texture over the entire lower
the longitudinal series of disk florets was attached next, by gluing them directly to the face of the block above the bare receptacle area. The areas between the florets were then varnished.

next, the corolla tops, anther tubes, styles and chaff tops were attached. Due to the differing shapes of the corolla tops, some had to be put in place before others; it was very important to note which ones these were before attaching the others. The floret tops were secured as their construction warranted, either by pegging and/or gluing.

In a general sense, I started at the apical point of Surface A (the receptacle "center") and worked my way to the outer rows (the receptacle perimeter). Construction and developmental stage of the floret tops dictated the order in which the individual pieces were put in place. The style branches of the two outermost whorls were the last pieces to be glued in place.

last to be attached were the pappus scales of the detachable disk floret and the pappus and chaff for the longitudinal series of disk florets. All were attached with white craft glue.

at this time, the pattern for the illustrated face of the model was drawn to match the outline of Side E, including the floret tops that were in place along the top edge. The illustration was drawn onto a lightweight cardstock with Berol Prismacolor pencils. Particular
attention was given to the edges, so that they would blend into the existing paint on the model. The finished illustration was sprayed with a matte sealer. A piece of 1/16" thick plexiglass was cut to the same outline as the illustration, the edges sanded and screw holes drilled in the corners and the flat face of the model. The illustration was fixed in place with artist’s spray mount and the plexiglass fastened over it with small brass screws.
D. Construction of the Grass Spikelet.

1. Pedicel and rachilla (Figure 16). This portion of the model was designed as a Y-shaped structure, the bottom of which would be attached to the base, with the floret parts attached to the top right arm. The left arm would represent the continuation of rachilla joints between each floret. Only one complete floret is shown on the model, although *Poa pratensis* commonly has several per spikelet (Figure 5). The glumes of the spikelet would be attached below the crotch of the “Y”.

   a. Pieces of 1" dowel rod were cut: one 4" section (piece A) and two 2-3/4" sections (pieces B and C). The distal ends of A and B were shaped and sanded to represent the cut end of a rachilla joint and the receptacle of a grass floret respectively, corresponding to previously published illustrations. The ‘receptacle’ piece was shortened approximately 1" during the rounding of its apex. These two pieces form the top of the "Y".

   b. Oblique angles were cut on the proximal ends of pieces A and B, as shown in figure D-1. They were then glued together, the glue allowed to dry, and the proximal surface sanded flat.

   c. The positions of two 1/4" pegs, connecting the proximal end of the A-B piece to the distal end of piece C, were marked, the holes drilled, pegs cut to size, and all pieces glued together. A hole was drilled in the proximal end of the "Y" (piece C) for later attachment to the model’s base.

   d. A temporary plywood base board was cut, a screw hole drilled and countersunk, and the pedicel/rachilla structure attached.
e. Drywall putty was applied to the joint areas of the "Y" (Figure 16); when dry, it was sanded for a smooth transition.

2. Construction of the glumes, lemma and palea

   a. Using measurements taken from the live spikelets and previously-prepared templates, I cut the pieces for all of the bracts from aluminum screen wire. An extra flange of screen was left along the edges that would be joined to make the keels of the bracts. The two glumes and the lemma each consisted of two pieces, while the palea, with its flat back, was composed of three. The pieces of each bract were sewn together with clear nylon thread. The bottom end of each was trimmed and shaped as much as possible to fit against the rachilla, and their positions were marked as depicted in Figure 17.

   b. Sections of 8 or 10 gauge aluminum wire were cut and shaped so that approximately 4 - 5" of it lay along the seam in the lower end of the bracts with 1-1/4" extended past the end to make a long peg (Figure 18).

   c. Holes corresponding to peg size were drilled in the rachilla. I made sure that the holes were angled correctly in order to give the proper vertical orientation to these bracts, their angle relative to the spikelet axis, and to permit their easy removal and reattachment (Figure 17). The peg hole for the lower glume happened to pass through the screw hole in the bottom of the pedicel. The screw was therefore shortened to the appropriate length.

   d. The screenwire forms were covered with thin sheets of polymer clay, frequently checking the fit against the sides of the rachilla. The aluminum wires
were pressed inside the seam and extra clay added to cover them. On the palea, the wire was pressed into one of the two seams and extra clay added at the base of the other seam for balance. The fit against the rachilla was rechecked. The bracts were then baked, usually laying on their sides or their open faces to prevent deformation during baking. Where needed, more clay was added around the peg at the base and baked again, to ensure good balance and a flush fit against the rachilla. The bracts were then filed and sanded as needed.

3. Construction of the stamens

a. From polymer clay, I shaped six individual pollen sacs (for the three pairs composing the three anthers) using previous measurements, drawings, and fresh specimens for reference. They show a range of maturity with respect to the size of the apical opening.

b. Each set of matching anther halves was pressed together back to back around the end of a 16 gauge steel piano wire, then separated and baked. The halves were filed, sanded, and puttied as needed.

c. Three lengths of 16 gauge steel piano wire were cut according to measurements of filament length, plus extra length to permit insertion into the floret receptacle and for that to be enclosed between the pair of pollen sacs. The wires were bent into the desired shapes on the model, taking into account that the lemma, palea, and glumes must be easily removable. I notched the distal ends of the wires several times in the area that would be enclosed within the anther halves,
in order to give the adhesive a better 'grip' on the wire. The same was done to the proximal end. Holes for the stamen filaments were drilled in the proper positions on the receptacle (piece B). Matching anther halves were glued around the apex of each filament wire using Liquid Nails adhesive. While I was NOT happy with the appearance and texture of this product, it did hold the anthers together and the seams were later smoothed with putty to hide the unsightly adhesive.

4. Construction of the lodicules
   a. Using templates and measurements, I fashioned two small balls of polymer clay into the shape of the lodicules, but without the apical membranous appendage. The lodicules were pressed lightly against the receptacle in the position where they would later be pegged, and the pieces then baked.
   
   b. A hole for a 1/16" peg was drilled in the bottom of both lodicules. Corresponding holes were drilled in the proper positions on the receptacle (piece B).
   
   c. The lodicules were sawed in half lengthwise.
   
   d. Pieces of organza fabric were cut to the same size as the outline of the lodicules, this time including the apical membrane. They were placed between the lodicule halves, pegs put in place, and the halves glued together.
   
   e. The apical ends of the lodicule were filed and shaped so that there was a gradual transition from the fleshy part to the membrane.
5. Construction of the pistil. This structure mainly consists of the ovary and the two stigmas, the style being so short that it was not easily represented.

   a. The ovary was carved from basswood. Two small holes were drilled side by side in the top. A 1/8" peg hole was drilled in the bottom of the ovary, and a corresponding hole drilled in the the correct position on the receptacle.

   b. Two sections were cut from the wide portions of a chenille "bumps" pipe cleaner, of lengths corresponding to previous measurements. Acrylic paint was mixed to the correct color for the grass stigmas and the sections dipped into it. The paint was worked thoroughly into the hairs and the excess squeezed out. This produced a spiky appearance that was further enhanced by clipping out small tufts of hairs here and there. The stigmas were allowed to dry thoroughly.

   c. A 1/8" dowel peg was cut and glued in place on the bottom of the ovary. The stigma branches were inserted and glued.

6. Painting and Assembly

   a. When all components were constructed and fitted correctly, the pedicel and rachilla were given two coats of primer. Using my earlier color matching scheme, acrylic paint was mixed to the approximate color of the stem and two coats applied. When it was dry, Prismacolor pencil details were added, such as shading on the pedicel and the cross-sectional view of the rachilla apex. A blending stick was used on the pencil surface after each layer of color. Rub-on letters were applied, then two coats of varnish. I had to be careful applying the first coat of
Varnish, as excess brushing caused the Prismacolor to run and blur or be carried into other areas.

b. The glumes, lemma and palea were given two coats of primer, then two coats of the pedicel color. Prismacolor details of shading and coloration patterns were added to all surfaces as appropriate (Plate K). The pieces were finished with rub-on letters and two coats of varnish. I painted the bract pegs as well, but the paint tended to chip off as they were inserted and removed from their holes.

c. The anthers and filaments were given two coats of primer, then two coats of the appropriate colors for each part. To simulate the remains of pollen in the apical openings, grains of medium-size model railroad ballast gravel were mixed with the appropriate color of paint and thinned white glue. Clusters of these grains were lodged in the crevices of the openings (Plate N). Individual grains were glued to the tufts of stigma hairs as well. Rub-on letters were applied, and the stamens then given two coats of varnish.

d. The lodicules were given two coats of primer, except for the apical membranes. Two coats of color were applied to the entire lodicules, including their membranes. Prismacolor venation details and shading were added, then a legend letter, and finally two coats of varnish.

e. The ovary was given two coats of primer and two coats of color. The stigmas were painted earlier. Pencil shading and a legend letter were added, then the pistil finished with two coats of varnish.
f. When all structures were painted and dry, I glued the pistil, lodicules, and stamens into their respective holes (Figure 19, Plate M). The lemma, palea and glumes were placed in their respective positions. Care was taken to angle the stamens to allow easy removal and replacement of the four bracts (Plate K).

F. Construction of the Plexiglass Covers

1. I had the components for each cover cut by professionals from 1/8” plexiglass. The covers were made large enough to clear the models by approximately two inches on all sides, and were designed as a simple box with the bottom open.

2. Rather than deal with the nasty adhesives necessary to glue plexiglass together, I opted for mechanical fasteners, i.e., L-brackets. These were brass, and were bolted on with small brass nuts and bolts. I used two for every seam of the cover, 16 in all. I fabricated my own brackets from a previously textured brass sheet that I happened to have at hand, but they could easily be made from another metal or purchased at a hardware store.

G. Hardwood Bases and Legends. The bases were designed to be large enough to accommodate the plexiglass covers with a 1/2 - 1" edge left outside the cover.

1. Oak planks or oak plywood were cut to size with a table saw or circular saw and sanded to a fine finish. Raw edges of the plywood were finished with strips of oak quarter-round molding with beveled corners.

2. Screwholes for attachment of the models were drilled and countersunk.
3. The inside perimeter dimensions of the plexi cover were marked, along with the position of 1/4" dowel pegs in the corners. 1/4" holes were drilled, and pegs cut to extend 1" above base. Their tops were sanded round.

4. Both bases and sets of pegs were stained, allowed to dry, and the pegs were glued in the holes in the bases.

5. Two coats of polyurethane varnish were applied to each base.

6. Legends were created that corresponded with the rub-on letters on the model parts, then laminated for protection.

7. Two U-shaped wooden frames were constructed from narrow strips of wood, slightly larger than the dimensions of each legend sheet, and painted black. Pieces of thin plexiglass were cut to the same size as the outer dimensions of the wooden frames. A half-circle was cut from the top center of each plexi piece. Small pilot holes were drilled in each corner of the plexi pieces and the frames.

8. The wooden frames were glued into position on the oak bases and the plexiglass sheets nailed in place with brass escutcheon nails. Legend sheets can thus be inserted or removed as needed for instructional use.

9. The finished models were then screwed permanently in place on the bases.

There was the sound of violins and applause, and graduate students everywhere danced with their advisors in the streets.
X. Discussion and Conclusions

To say that building these models was a "learning experience" would be a considerable understatement. This observation is at the heart of an important change in my philosophical attitude toward the project. Somewhere along the way, I realized that it was more about process and less about product than I had anticipated. I don't mean to negate all the aesthetic concerns that I expressed in the introduction concerning the finished models, but, in retrospect, I can say that the experiences of designing and building were far more important to this project than simply having two finished models at the end. If I can apply the principles of the scientific method to this half-creative/half scientific endeavor, I would say that my hypothesis was that I could design and build durable, functional, educational and aesthetically pleasing models using the procedures that I developed. Of course, the alternative hypothesis, that my designs and procedures would not produce the desired results, also existed. Yikes! No one, least of all me, wants their grand experiment to "fail," but support for an alternative hypothesis is always as valid a result as is support for the original hypothesis. So it was that I began to see the worth of this project not only in terms of its "success," but also in relation to its experimental aspect, and even in terms of its shortcomings.

I know that the structures that I built are more fragile than I'd hoped they would be. Only using them in the classroom will show whether or not they are truly understandable and accurate. On the brighter side, they are as fully functional as I had envisioned, and quite attractive, if I do say so myself! Time and use of the models will determine which hypothesis is supported in the end.

In the interests of people who might be using this report as background material for similar
endeavors, I would like to point out some of the more specific problems that I was not able to resolve to my satisfaction, as well as some of the best features of the model designs. Perhaps this will provide a means to improve upon some of my choices of materials and methods.

First, the bad news: as pleased as I was with the appearance of the ray florets on the sunflower model, they may be its greatest weakness. The weight of the large ligule produces a lot of stress on the juncture of the corolla tube and corolla blade, and on the basal end of the tube as well. I first noticed signs of this stress in the form of vertical cracks at the base of the removable corolla tubes, particularly along the path of the copper wires. The amount of space between the ovary peg and the inside of the tube also contributes to this; the more space, the more play the entire corolla has, and the more stress is produced on the tube. I noticed another crack which appeared horizontally along the basal edge of the ligule, just above the top of the tube, on one of the corollas. I know this was a direct result of the weight of the ligule, and also a result of the more acute reflexion in that particular corolla than in the others. Unfortunately, the cause of most of these problems lies in the qualities of the polymer clay used throughout the project. It is both heavier and less rigid than I’d hoped; a lightweight plastic would probably be more suitable, but the technology required to form it might be prohibitive, as it was for this 'low-tech' project.

I can suggest several ways in which these stress problems could be remedied: most importantly, reduce the weight of the corolla blade, either by using a lighter material to cover the screenwire, or by shortening the length of the blade, or both! The length of the ray floret corollas as they are now lends them a particular gracefulness, but the weight may cause problems if the ray corollas are left in place for long periods of time. Another improvement might be the use of steel
piano wire in place of the copper wire "veins" (Figure 12). Copper wire is sold in a very soft condition, whereas piano wire of the same gauge (16) comes in a rod form with great springiness. I believe the tensile strength of the steel would give much greater support to the corolla structure, although it is a little more difficult to work with. The advantages of the steel wire could be augmented by forming the ray corollas so that they arch more vertically upward with less "drooping" downward. This would help to center the weight of the ligule more closely to the peg.

A final aid to relieve the stress on the ray corollas would be to ensure that the u-shaped aluminum brackets are positioned higher than the top of the pegs, and as high as possible while still accommodating the corollas' flared areas. This would make the bracket support its share of the weight and relieve some of the stress on the base of the corolla tube.

One other area of stress was found at the joint of the ovary and the corolla tube on the detachable ray floret. The white e*raft glue was simply not strong enough to cope with the weight of the ligule pulling back on it. One way to alleviate this strain would be to eliminate all space between the ovary peg and the corolla tube walls, and, more importantly, to decrease the weight of the ligule and center it over the peg as described above. Another improvement might be to eliminate the joint between the ovary and the corolla and fabricate the removable floret in one continuous piece, with the peg encased solidly in the center.

My other complaints with the sunflower model were basically cosmetic: I was not happy with the appearance of the dimples on the cleared area of the receptacle (Plate C). They were drilled out with a round-headed rotary file, and were more suggestive of a golf-ball surface than a receptacle surface. I think I should have eliminated the drilled dimples and relied on the spray-texture to represent the rough surface left by removal of the disk florets. I was also disappointed
in the glossiness of the varnish used on both models. It produces a glare which I find distracting, and detracts from the appearance of the models, especially in photographs. The product I chose was supposed to have been a 'satin' finish (a medium gloss), but I suspect the 'matte' version would have been more appropriate.

Happily, my complaints with the finished grass model were fewer. I had some trouble with the steel-wire filaments of the stamens; the weight of the anthers would cause them to break the glue-bonds at their bases and rotate within the holes. I think that a stronger adhesive, such as an epoxy, along with notches in the basal ends of the filament wires, would take care of this problem.

I would also position the bracts of the grass model more closely together, especially the lemma and palea. I had originally intended that the floret would be 'closed' (Figure 17), but that the bracts would be removable. I felt that there would be a sense of discovery or dissection in having to take them apart in order to see the sexual parts of the grass floret. During the course of construction, their positions were relaxed somewhat, so that now one can almost see everything without needing to remove the bracts (Plate L).

Now for the good news: in terms of visual impact, both models were very successful (although I may be somewhat biased in that opinion). They are photorealistic to a degree, but without losing the nature of being a handcrafted object, which I believe is part of their greatest appeal. This quality is expressed in subtle ways, such as leaving vestiges of the sculptural finger imprints in the laminar clay surfaces, and in the gestural sense of the paint and pencil details. I believe that the marks are significant because they indicate the presence of a maker. They identify the models as fabricated, interpretive objects, rather than just anonymous imitations of natural structures. However, these little bits of artistic license do not detract from the accuracy or
The use of attractive wood and hardware on the bases and covers was also intended to contribute to the overall sense of craftsmanship. While doing the research for this project, I was often impressed by the fineness and charm of botanical illustrations in my older sources. For the most part, they retained the quality of fine aesthetic presentation without sacrificing the valuable mimetic properties. To me, they are a reminder of an age (before the advent of practical plastics) when aesthetic appearance was an important consideration, and craftsmanship was as much a visual quality as a functional one, even in the most basic tools and scientific equipment. I hope that the finished models, complete with bases and covers, will have some of the same presentational charm as those old illustrations and be an acknowledgement of my respect for the artists who created them then and those who do so today.

In terms of the design and functional requirements of the models, with the exceptions mentioned above, everything worked. All of the intended removable parts are in fact self contained and removable. Each morphological surface and structure has been accurately represented, corresponding to the needs of the courses for which they will be used. In the cases where I could not conform to absolute accuracy (e.g. the completely solid receptacle block, or the presence of support brackets for the ray florets), I think that those features have been disguised well enough that they do not detract from the model as a whole. I am especially pleased with the design of the grass spikelet model. Structurally, it is quite stable and seems as if it will be durable as well. I hope that it will provide many years of use. The sunflower capitulum, on the other hand, may require more careful handling, but with that consideration, I think it, too, will be very functional. Perhaps any limitations that these models have will be inspiration for another such
project and an aid for someone else in avoiding similar pitfalls.

The success of this project is also encouraging in that these models can be thought of as prototypes. With simplification, the basic designs could be suitable for commercial production in poured plastics or other materials.

All in all, I feel that most of the requirements of my original objectives have been met and that the project was successful. The challenges of formulating a design and the problem-solving aspects of construction were very personally rewarding. Prior to this project, my creative efforts were usually worked out in detail and completely "finished" in my head before ever making the first sawstroke. So, it was an eye-opening and often trying experience to adapt my designs to cope with unfamiliar materials and processes. Dare I say that the designs 'evolved' successfully? Only time will tell -- and that fits the analogy as well. It would be an exaggeration to say that the models are as "fit" in the Darwinian sense as the natural organisms that inspired them, but I hope that they will still be passing on information for many generations to come.
XI. Acknowledgements

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XII. Source List


APPENDIX I

FIGURES
Figure 1. *Helianthus annuus*, sunflower. a) leaf and flower bud, b) head of flowers, showing the areas of ray and disc [florets], c) head of flowers, showing the involucral bracts and the corollas of the ray [florets], d) head of flowers, longitudinal section, showing the ray [florets] (marginal) and disc [florets] above the involucral bracts and compound receptacle, e) ray [floret], showing the floral cup (adnate to the inferior ovary), the corolla (even the tips of the petals coalescent), and not stamens or style (the ovary being sterile), f) disc [floret] subtended by a chaffy bract, g) disc [floret], showing the floral cup (adnate to the inferior ovary), the pappus of scales, the tubular corolla, the anther tube, and the style and stigmas, h) disc [floret], dissected, showing the separate filaments. (from Benson, 1959; p. 299)
Figure 2.1. Basic plan (top view) of the sunflower capitulum model, showing the positions of a) ray florets, b) whole removable ray floret, c) cleared area of the receptacle, d) removable single disk floret, with subtending receptacular bract, e) longitudinal disk floret maturation series, f) disk floret tops, and g) illustration of longitudinal cross-section of the capitulum.

Figure 2.2. Basic plan (side view) of the sunflower capitulum model, showing the positions of a) brackets for supporting the removable ray corollas, b) phyllaries, c) illustration of longitudinal cross-section of the capitulum, and d) peduncle.
Figure 3. Various sides/surfaces of the wooden block, lettered for reference in the text.
Figure 4. Approximate numbers of florets per whorl on one quarter of a capitulum, according to Fibonacci's number series, based on sample measurements.
Figure 5. *Poa pratensis*. a) plant, x 1/2; b) spikelet, x 5; c) floret, x 10. (from Hitchcock, 1950; p. 114)
Figure 6. General morphology of *Poa*. Spikelet: a) lower glume, b) upper glume, c) lemma. Floret: d) lemma, e) palea, f) stigma, g) stamen, h) ovary, i) lodicule. (from Benson, 1959; p. 357)

Figure 7. Lateral compression of a spikelet.
Figure 8. Major steps in the process of carving the wooden receptacle block.
Figure 9.1. Longitudinal cross-section of side B/D of the wooden block, showing attachment of the receptacle extension and aluminum bracket, and attachment of the peduncle to the receptacle. a) 1/4" diameter wooden pegs, b) cylindrical peduncle block, c) drywall putty, d) polymer clay receptacle extension, e) aluminum support bracket with screws.

Figure 9.2. Top and bottom views of wooden block with receptacle extension and aluminum support bracket in place. a) original wooden ledge, b) polymer clay extension, c) aluminum bracket, d) aluminum bracket shown with screws, e) peduncle.
Figure 10. Various construction methods for disk florets in the maturational surface on Side B of the capitulum model. a) solid polymer clay corolla tube, b) carved wooden ovary, c) 1/2 wooden ball, d) hollow polymer clay corolla tube, e) polymer clay closed stamen tube (those constructed of chipboard would be placed in the same position).
Figure 11. Longitudinal section of the removable disk floret showing its construction, placement on the receptacle and receptacular bract. a) style branch, b) stigmatic surfaces (jute fibers), c) style (plastic pipe), d) stamen tube (chipboard), e) corolla tube (polymer clay), f) fabricated wooden tube, g) 3/4" wooden ball, h) 1/8" wooden peg, i) polymer clay tube, j) cloth pappus, k) ovary (carved wood), 1) receptacle block surface with dimples, m) peg hole for receptacular bract, n) cloth receptacular bract, o) 1/16" wooden peg.
Figure 12. Longitudinal section of model showing attachment of ray floret ovary to the receptacle block, with removable corolla in place. a) corolla blade (ligule), b) screenwire armature, c) aluminum bracket, d) copper wire, e) corolla tube, f) ovary peg, 1/4" wooden dowel, g) ovary, h) receptacle extension, i) aluminum bracket, j) receptacle block.
Figure 13. Longitudinal section of whole removable ray floret (#5), showing attachment to the receptacle. a) style, b) screenwire armature, c) copper wire, d) wooden peg, 1/4" dowel, e) pappus, f) ovary, g) aluminum plate, h) brass tube.

Figure 14. Top view and longitudinal section view of reinforcement structures for the removable ray floret peg. a) aluminum bracket, b) receptacle extension, c) wooden receptacle block, d) aluminum plate with screw, e) brass tube, f) peg hole.
Figure 15. Longitudinal sections of disk floret tops and chaff lobes on Side A of the capitulum model. a) solid polymer clay closed corolla tops, b) 1/16" wooden pegs, c) cloth chaff lobe apices, d) hollow polymer clay corolla apices, with lobes closed and reflexed, e) solid polymer clay closed stamen tube, f) chipboard stamen tube, 1/8" plastic style with branches (jute fiber stigmatic surfaces not shown), g) wooden block.
1/8" wooden pegs

drywall putty

1" wooden dowel sections

Figure 16. Longitudinal section of the rachilla/pedicel structure of the spikelet model.

Figure 17. Placement of the glumes, lemma and palea on the rachilla and pedicel of the spikelet model. a) lower glume, b) upper glume, c) lemma, d) palea. The actual placement of the bracts turned out to be slightly more relaxed and open than this diagram indicates.
Figure 18. Cutaway view and cross-section showing structure and placement of the bracts on the rachilla/pedicel of the grass spikelet model. a) aluminum wire, b) screenwire armature, c) polymer clay layer.

Figure 19. Cross-section of grass spikelet structures. a) rachilla joint, b) lower glume, c) upper glume, d) lemma, e) palea, f) receptacle apex, g) stamen, h) lodicule, i) ovary.
APPENDIX II

PHOTOGRAPHS
Plate A.  Completed sunflower model facing sides B and D.

Plate B.  Side B of sunflower model during construction, showing different components of the disk floret maturation series, detachable disk floret and detachable ray floret.
Plate C. Detail of completed sunflower model, showing sides A, B, C and D.

Plate D. Side A of sunflower model during construction, showing placement and different stages of the disk floret apex components.
Plate E. Detail of side A of finished sunflower model showing disk floret apices.

Plate F. Detail of disk floret maturation series on completed sunflower model, showing young disk florets with receptacular bracts.
Plate G. Detail of disk floret maturation series, showing upper corollas, anther tubes and style branches of oldest florets.

Plate H. Sides F and G of completed sunflower model, showing phyllary series and ray florets in brackets.
Plate I. Removable ray floret of sunflower model. Pappus has not yet been applied.

Plate J. Detachable disk floret and receptacular bract of sunflower model.
Plate K. Completed grass floret model.

Plate L. Detail of completed grass floret model, showing attachment of bracts.
Plate M. Detail of completed grass floret, showing placement of pistil, stamens, and lodicules without bracts in place.

Plate N. Detail of anther of completed grass model.