

Silk Batik

Using Beeswax and Cochineal Dye: An interdisciplinary approach to teaching entomology

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“**I**nsects, Science, and World Cultures” is a general education course for non-science majors and pre-service teachers (kindergarten-grade 12) at Washington State University. It offers an interdisciplinary perspective of the global impact of insects and their products on human cultures and scientific research, in both historical and contemporary contexts. The course comprises two 50-minute interactive lectures/discussions and one 3-hour laboratory session per week. By design, the course emphasizes inquiry-based and experiential learning, and requires students to link new information about entomology to their prior experiences and knowledge from various disciplines. Educators have long advocated such interdisciplinary pedagogical approaches to foster higher-order thinking skills in students (Bloom 1956, Osborn and Wittrock 1985).

The silk/cochineal/batik unit spans two weeks, and information on relevant insects and their products are contextualized and integrated through “hands-on” activities that explore several topics. Our paper highlights our approaches to these topics, which include the 2,000-year history of the silk trade, the biology and natural history of silk moths and cochineal scales, the past and current significance of cochineal, and principles of fabric dyeing as illustrated by batiking on silk fabric using beeswax and cochineal.

SILK

The Silk Road and Silk Industries

We begin the unit with a historical look at sericulture and the far-reaching impact of the silk industry on human history (Hertz 1909, Cloudsley-Thompson 1977, Cherry 1987, Berenbaum 1995, Thubron 2007). Sericulture, or rearing silk moths and reeling to produce silk thread (Peigler 1993), first began around 2000–3000 BCE in China (Cloudsley-Thompson 1977, Cherry 1987, Silk Road Foundation 1997-2002; Fig. 1a-b). There is a rich folklore surrounding its origins, partially because silk production in this region remained a secret, under penalty of death, for more than two millennia (Liu 1952, Cloudsley-Thompson 1977, Berenbaum 1995). Much of the silk industry relied on key trade routes, known as the “Silk Roads” (Fig. 2), to transport its valuable commodity (Cloudsley-Thompson 1977, Berenbaum 1995). Peak



Fig. 1a-b. German chromolithographic Liebig meat extract trade card depicting a) rearing silk moths and b) text on back of card.

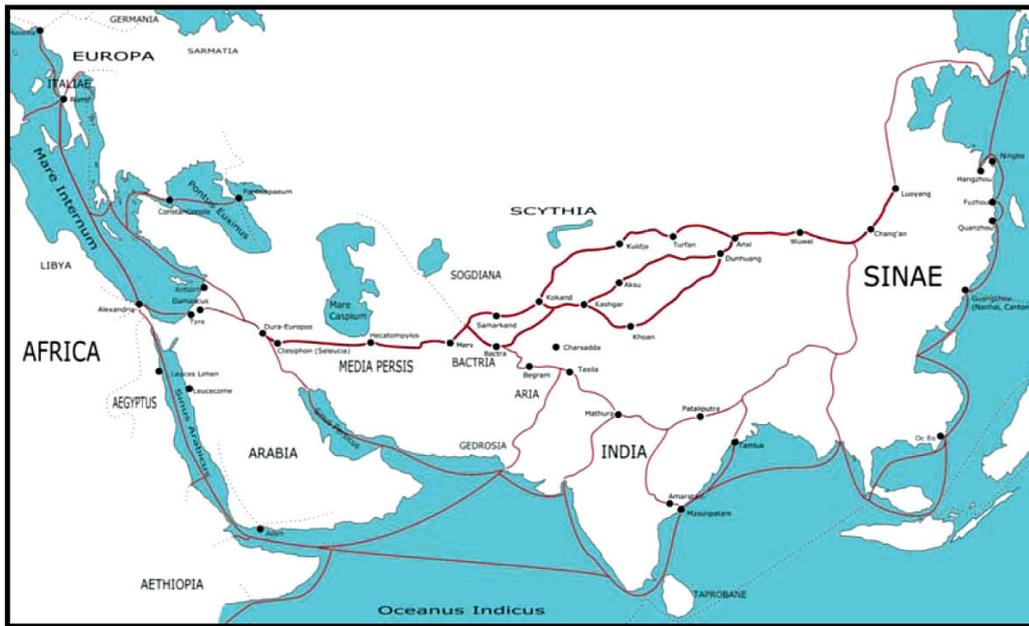


Fig. 2. Goods, technologies, religions, and knowledge traveled between Asia and Europe along the “Silk Roads.” Map illustrates trans-Asia silk trade routes from ca. 500 BCE to 500 CE. (Geographical labels for regions adapted from Geography of Ptolemy (ca. 150 CE), although some trading center names date from ca. 400 CE.) Source: http://commons.wikimedia.org/wiki/Image:Transasia_trade_routes_1stC_CE_gr2.png

periods of trade spanned several centuries during the Han Dynasty (200 BCE–200 CE), Tang Dynasty (618–697 CE), and Great Mongol Empire (13–14th century) (Silk Road Foundation 1997-2002). In the 6th century, Byzantium became a leader in sericulture after silk-worm eggs were smuggled out of China by two monks (Cherry 1987, Berenbaum 1995). Silk production then spread rapidly throughout Europe (Hertz 1909, Cloudsley-Thompson 1977, Berenbaum 1995, Ma 1996). During the 19th century, several attempts to develop a successful sericulture industry failed in the United States (Science 1885), when thousands of mulberry trees were planted in what became known as the “*Morus multicaulis* craze” (Cherry 1987). Interest in U.S. sericulture also led to the ill-fated importation and accidental release of the pestiferous gypsy moth (*Lymantria dispar* L.) in the 1860s by Trouvelot, who was attempting to breed disease-resistant silk moths (Liebhold et al. 1989, Berenbaum 1995). An American silk weaving industry flourished in some northeastern cities (Fig. 3) prior to the Great Depression (Scranton 1985, Ma 1996, Northampton Silk Project 2002, Field et al. 2007).

Bombyx mori

Larvae of *Bombyx mori* L. (Lepidoptera: Bombycidae), commonly termed silkworms, are the source of commercially produced silk. This insect has been domesticated for 35 centuries (Cloudsley-Thompson 1977, Berenbaum 1995), and its historical and modern



Fig. 3. Seal of city of Northampton, MA. Silk moths in the outermost ring of the seal represent the city's silk industry, which involved the rearing of silkworms in a short-lived attempt to create a self-sustainable utopian society (City of Northampton 2008).

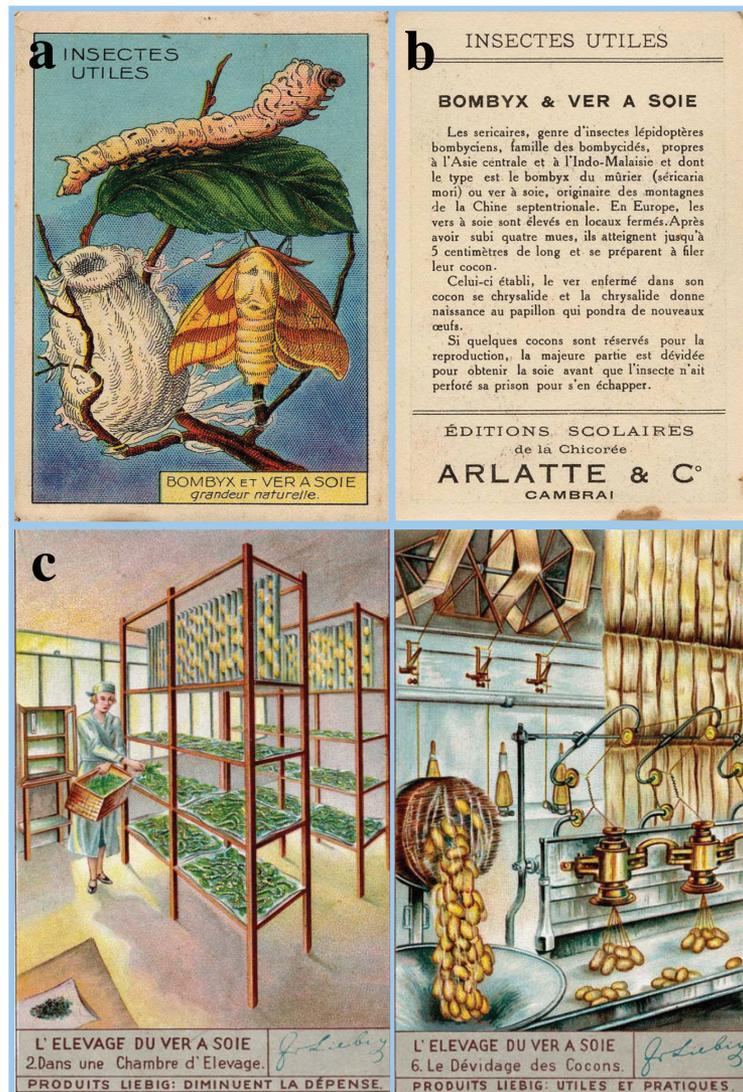


Fig. 4a-d. Trade cards printed in French. Card labeled Insectes Utiles (Useful Insects) produced by Arlatte and Co. depicts a) life stages of the silk moth with b) text on back of card. Cards labeled L'elevage du ver à soie (Rearing of silkworm) depict c) rearing room and d) reeling of cocoons.

role in sericulture, including rearing, silk reeling, and weaving, have been depicted in artistic color plates (Casalis and Guadalupi 1980) and antique trade cards (Figs. 1a-b, 4a-d). We introduce students to these interdisciplinary connections and also use *B. mori* as a vehicle to teach scientific concepts (taxonomy, binomial nomenclature, insect metamorphosis, and endocrinology). In addition, we discuss the physical properties of silk (e.g., it is the strongest known natural fiber) and some impressive facts (e.g., 3,000 cocoons are required to produce one pound of silk) (Berenbaum 1995).

Silk Road Classroom Exercise

After learning about sericulture and silk moths, students participate in an in-class active learning exercise called the “Web of Knowledge.” In preparation, each student completes a homework assignment that requires research on particular people, places, ideas, technologies, and products (trade and cultural items) historically associated with the silk roads (Box 1). Students gather information about their topics on-line, cite Web sites, and return to class ready to share their findings.

The goal of the Web of Knowledge exercise is for students to communicate their findings and connect them to those discovered by their classmates. To begin, one topic is randomly selected from

Box 1. Homework assignment to prepare students for the Web of Knowledge activity.

Can you make the Silk Road connections? Name _____

Part I: Background Questions
Read the article at <http://www.ess.uci.edu/~oliver/silk.html> about the Silk Road and answer the questions below, which you will turn in on the day of the in-class Silk Road “Web” activity. Be sure you have sufficient information to participate in our class debriefing on “Web” day (Part II, below).

Questions to answer and turn in:

1. What is the Silk Road? Why is the term “Silk Road” something of a misnomer?
2. Where is it? When did it begin? When was it most important?
3. What are the geography, climate, and landscape of the area?
4. What was transported along the route? (Remember: things went both ways and not all were physically tangible.)
5. What happened to the Silk Road during the beginning of the 18th century, and why? (Think along political and physical lines.)
6. Why was there a renewed interest of the Silk Road in the 19th and 20th centuries? What did archaeologists and other scientists find? Why did those explorations finally end?
7. And today...why are the routes currently being preserved?

Part II: Key Terms
On “Web” day we will become sleuths, piecing together various elements of the Silk Road to form a cohesive, comprehensive picture. For our in-class activity, we will figure out how the information you and your classmates have obtained relates to the history and development of the Silk Road. Using the Silk Road

the list in Box 1 (e.g. “Carpini”) and a ball of twine given to “student A,” who was assigned that entry. Student A then informs the class that Carpini was a Franciscan friar from Italy who traveled to the Mongol capitol in 1245, where he met Guyuk Khan, third son of Genghis Khan, whose grandson was Kublai Khan, confidant of Marco Polo. Carpini could thus serve as a connection to the Mongol Empire, Franciscan friars, Genghis Kahn, or even Marco Polo. If student B, who was assigned “Marco Polo,” announces a connection to Carpini, then student A will hold onto the end of the twine and toss the twine ball to student B. Student B can then tell the class about Marco Polo, his merchant family’s travels, his visit to the court of Kublai Khan, and the spice trade along the silk roads. Student C, who was assigned “spices,” can readily announce a link to Marco Polo, at which point student B will hold onto a length of twine and toss the twine ball to student C. The exercise proceeds as such until all terms (Box 1) have been “connected” and students have created an intellectual as well as physical “Web of Knowledge” (Fig. 5).

COCHINEAL

During the Colonial era, as silk from China made its way to Europe’s finest textile markets, so did cochineal from the New World. Cochineal influenced commerce and politics on a global scale and has a rich and “colorful” history. To augment the interdisciplinary nature of the silk/cochineal/batik unit, we provide two additional lectures:

Box 1. (continued)

website (and additional websites if you wish), define/describe each term that is specifically highlighted for you. Think about how the development/culture/etc. of the Silk Road was affected by each term.

Turn in your findings on “Web of Knowledge” day. Be prepared to participate in an activity in which you will share your information orally with the class.

Note to reader: We highlight two to three terms from each column below to create individual student assignments.

People/Places	Ideas/Other	Technology/Products
Zhang Qian & Xiongnu tribe	Gandhara culture	Sogdiana and Sogdians
Xuan Zhuang	British Museum & British Library	Paper making
Parthians	Dunhuang	YuMen Guan
Carpini	Greek influences (after 330 BC)	9th century Chinese porcelain
Marco Polo	Great Goose Pagoda	Invention of printing
Franciscan friars	Christianity	Spices
Palmyra	Buddhism	Game of chess
Genghis Khan/ Mongol Empire	Tang Dynasty	Gunpowder
General Marcus Crassus	Great Wall of China	Library in Mogao grottos
Von Richthofen	Grottos	Astana tombs
Sven Hedin	Han Dynasty	
Seres	Sea Silk Route & “tribal politics”	



Fig. 5. Students create a “Web of Knowledge” by sharing information and making connections regarding the silk roads.

one on the historical significance of cochineal dye, including its production and the insect’s natural history; the other on basic principles of fabric dyeing, including mordanting and batikting.

Cochineal: Historical Significance

In our modern world, red fabrics are typically colored with cheap, readily available synthetic dyes. But prior to the manufacture of aniline dyes in the 1860s, people relied on natural dyes to produce red hues (Greenfield 2006). Cochineal was used to dye military uniforms, including those of British officers—the “redcoats” of the American Revolutionary War (Greenfield 2006)—and those of the Royal Canadian mounted police (DeFelice 2004). The red stripes in the original Star-Spangled Banner were dyed with cochineal and madder from the plant *Rubia tinctorum*, a member of the family Rubiaceae (Molotsky 1999).

Many rubiaceaeous species from the Old and New World have been used to produce red dyes, but only a few animal species serve this purpose, including three genera of scale insects (Donkin 1977). In the Old World (Armenia, Azerbaijan, Georgia, Turkey, Iran), *Porphyrophora polonica* (Hemiptera: Coccidae) yields Armenian red dye, while *Porphyrophora hameli* (Eastern Europe, Russia, Asia Minor) produces St. John’s blood, or Polish cochineal. In the Mediterranean, *Kermes* species (Hemiptera: Kermesidae) produce oak-kermes (Greenfield 2006). In the New World, nine (or possibly ten: see Portillo and Viguera 2006) species in the genus *Dactylopius* (Hemiptera: Coccidae) yield cochineal (Fig. 6a-b), the most famous insect-produced dye. *Dactylopius coccus* Costa is about twice the size of feral species and produces *grana fina*, the most valuable cochineal dyestuff (Donkin 1977). The rich crimson and scarlet hues associated with cochineal as a dye are due to carminic acid, an anthraquinone produced by females that may serve as a feeding deterrent to ants (Eisner et al. 1980) and appears to play a role in *D. coccus* immunity (Hernández-Hernández et al. 2003).

Long before Europeans “discovered” the New World, *D. coccus* had been domesticated and cochineal was culturally embedded in many ancient groups. Cochineal-dyed textiles from 2,000 years ago are known from burial sites in Peru (Greenfield 2006), and cochineal dye was used in pre-Columbian Mesoamerica, Mexico, and South America (e.g., Aztec, Nazcan, and Incan civilizations) (Donkin 1977, DeFelice 2004). Indeed, because of its pre-Colonial occurrence in both Mexico and Peru, it was long debated whether *D. coccus* originated

in the northern or southern hemisphere (Rodríguez et al. 2001). Recently, the disjoint geographic distribution of this species, coupled with a recent phylogenetic reconstruction of the genus *Dactylopius*, suggests that it originated in South America and was transported via pre-Columbian sea routes to Mesoamerica and Mexico (Rodríguez et al. 2001).

After the conquistadors laid siege to the Aztecs in 1521, dried cochineal was shipped to Spain and soon proved highly profitable (Greenfield 2006). Priests, royals, and the well-to-do of Europe began demanding fine fabrics dyed with cochineal, which offered greater durability and intensity of color than the Old World reds, particularly when mixed with a mordant such as alum (Marichal 2006). Sumptuary Laws, as well as the high cost of cochineal-dyed fabric, forbade commoners from donning such fancy attire (Elizabethan Sumptuary Laws 2001). The ability of cochineal to color fabrics of animal origin (i.e., silk and wool), coupled with its ease of exportation, fueled its meteoric rise as a global commodity (Greenfield 2006). By 1625, cochineal had revolutionized the dyeing industry (Lee 1951).

Initially, Spain had a monopoly on cochineal imports, and in 1557, received 50,000 pounds of cochineal from current-day Mexico, which would grow to more than 150,000 pounds in 1574 (Greenfield 2006). In 1630, cochineal ranked second to silver among exports from New Spain and was worth 57% of its weight in silver (Lee 1951). To assure its cochineal monopoly, Spain kept the origin of the dyestuff a carefully guarded secret and passed laws that forbade its trade by foreigners (Greenfield 2006). Nevertheless, substantial amounts of this valuable commodity entered Europe by illicit means, often by piracy and raiding of Spanish fleets (Lee 1951).



Fig. 6. French trade card produced by Arlatte and Co. depicting Insectes Utiles (Useful Insects): a) female (above) and male (below) cochineal insects on cacti and b) text on back of cochineal card.

Because of cochineal’s importance, 17th-century European naturalists attempted to elucidate its secret origin by microscopic inspection. Leeuwenhoek prematurely concluded that cochineal was a seed akin to a dried blackcurrant (Greenfield 2006), but in 1704, he sent morphological drawings to the Royal Society of London based on his microdissections of cochineal scales (Fig. 7). The only material available to Leeuwenhoek for his investigations were dried “particles” (i.e., female cochineal insects) from the dyeing industry, yet remarkably, his drawings and descriptions not only included the

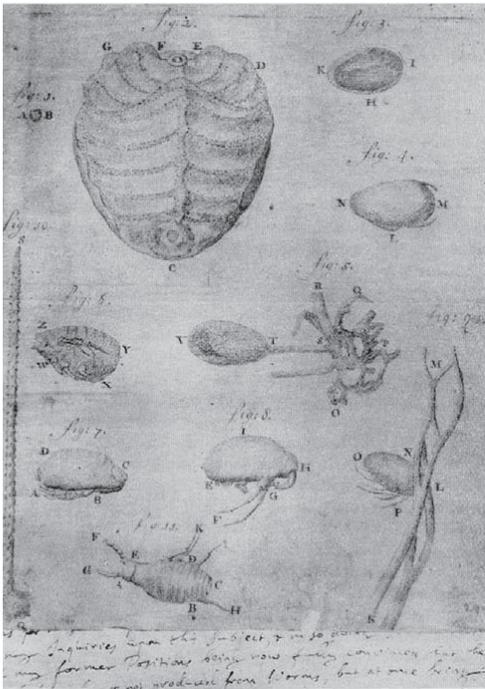


Fig. 7. Leeuwenhoek's drawing of his microdissection of cochineal insects, sent to the Royal Society of London in 1704 and published the same year in their Philosophical Transactions.

female insects, but also eggs, embryos, and appendages (mouthparts, antennae, and legs) (Cole 1951)¹.

Eventually, the true nature of cochineal was discovered, including the fact that *Dactylopius* species are parasitic insects on cacti, most in the genus *Opuntia* (Portillo and Vigueras 2006; Figs. 6a-b, 8a-b).

Until the late 1700s, the bulk of the world's cochineal supply came from small *Opuntia* patches cultivated by impoverished Mexican aborigines in southwestern townships around Tlaxcala, Mixteca, and Oaxaca (Donkin 1977). There were also a few large plantations (*haciendas*) of perhaps 60,000 cacti (termed *nopals*; Fig. 8a), owned by wealthy Spaniards and tended by local peasants (Donkin 1977). In 1839, Oaxaca led the world in cochineal production with 900,000 pounds, but by the 1850s, Guatemalan exports reached nearly two million pounds per year (Marichal 2006). Cochineal insects were introduced into Spain's Canary Islands in the 1820s and by 1875, cochineal exports from this region exceeded six million pounds per annum (Donkin 1977).

Some New World cochineal exported to Europe found its way back to the American southwest by a circuitous route. Bright red colors were highly prized by Navajo craftswomen, whose weavings were unparalleled (Fig. 9), but indigenous plants did not yield red dyes and cochineal insects and dye were apparently unknown to the Navajo (Schneider 1987, Whitaker 2002). Indeed, no evidence exists that the Navajo ever produced their own handspun, cochineal-dyed yarns (Whitaker 2002). Instead, their weavers tediously raveled and respun bayeta, a cochineal-dyed woolen cloth imported from Europe, bolts of which were transported across the eastern United States and west along the Santa Fe Trail until they reached trading posts on Navajo reservations (Rodee 1981, Whitaker 2002). Bayeta red became so popular during the 1800s that few blankets were made without it, until the early 1880s, when the railroad began bringing synthetic aniline dyes and aniline yarns to the Navajo weavers (Rodee 1981, Kaufman and Selser 1985). The use of garish, aniline-produced

¹Swammerdam, an early student of entomology, also discovered that cochineal was an insect, but succumbed to malaria with his findings unpublished (Greenfield 2006).



Fig. 8a-b. German chromolithographic Liebig meat extract trade card depicting a) workers tending cochineal insects on cacti before processing them and b) text on back of cochineal card.

colors marked the end of the Classic period of Navajo weaving, and was symptomatic of a revolution in the textile industry catalyzed by the innovative success of William Perkin.

In 1856, Perkin, a student at London's Royal College of Chemistry, was attempting to synthesize quinine, a natural product from a tree native to South America and valued as the only known treatment



Fig. 9. United States 22-cent stamps issued in 1986 that depict Navajo textiles. The Navajo incorporated cochineal-dyed materials into their weavings before the advent of aniline-dyed yarns.

for malaria (Greenfield 2006). While experimenting with aniline, a coal-tar derivative, Perkin produced a dye that turned silk a shade of lilac. He developed the technology to manufacture the dye, and by 1859, Londoners were sporting clothing dyed with “Perkin’s mauve.” In the 1870s, a new artificial red dye termed alizarin hit the market, and cochineal exports plunged worldwide (Greenfield 2006).

Cochineal: Interactive Session Assignment

During the introductory lecture on the historical significance of cochineal, we give students a homework assignment to search grocery stores for items containing cochineal (or its derivatives: carmine, carminic acid, and E120) as listed on nutritional information labels. Students share their findings in class during a brief interactive session on modern uses and production of cochineal, during which they create a master list of cochineal-containing food products. The interactive session is a prelude to the lecture on fabric mordanting, dyeing, and batikting.

Cochineal: Modern Uses and Production

In the wake of synthetic reds, cochineal became marginalized to niche markets, including use in biological stains and traditional arts and crafts. Its commercial viability was not restored until 1976, when the U.S. Food and Drug Administration (FDA) banned the use of the dye FD&C Red No. 2 due to carcinogenicity reports (Greenfield 2006). Because cochineal and carmine extracts had FDA approval, the food, pharmaceutical, and cosmetic industries began using these safe, cost-effective additives (Greenfield 2006). Cochineal is currently incorporated as a coloring agent in paints, lipsticks, rouge, cough syrup, and various food products, such as yogurt, grapefruit juice, popsicles, artificial crabmeat, and many types of candy (Gogoi 2006). We have students debrief the class on their grocery store findings (*Interactive Session Assignment*, previous section) and then discuss current health concerns in the United States and abroad regarding cochineal, such as human allergic responses (Baldwin et al. 1997) and ethical issues raised by vegetarians and animal rights groups (Skrzycki 2006, Barton 2007).

Today, 85-90% of the world’s cochineal comes from Peru (Rodríguez et al. 2006). Remarkably, most originates in Ayacucho, a poor Andean community (Holligan 1999, Rodríguez et al. 2006) with an estimated 100,000 households harvesting cochineal (Rodríguez et al. 2006). In 1997, Peruvian cochineal exports were worth \$33 million (Holligan 1999), and the industry is reportedly growing at 15% per year (Kaste 2003). However, cochineal production continues to be a labor-intensive endeavor (Smalley 2007; compare Figs. 10 and 11a-b). Gravid female *D. coccus* are “seeded” by hand onto prickly pear cacti (*Opuntia* spp.). Nymphs require 3 to 4 months to mature, during which time the scales must be guarded from predators and competitors, and the cacti pruned and protected from disease and cold temperatures (Portillo and Viguera 2002, Greenfield 2006). Adult females, which are apterous and sessile, are hand-harvested two to three times per year and killed by boiling or drying in the sun, in ovens (Fig. 8a), or on hotplates (Donkin 1977, Smalley 2006). Approximately 70,000 dried females yield one pound of dyestuff (*grana cochinilla*), worth about \$3.50/kg to farmers (Smalley 2006).

METHODS

Basic Principles of Fabric Dyeing

Since prehistoric times, humans have used plants and animals to dye fibers and textiles (Adrosko 1971, Donkin 1977, Maiwa



Fig. 10. Harvesting cochineal (ca. 1700). Harvesters removed cochineal insects from the nopal (cactus) using an elongated instrument, and placed them in shallow bowls. A Spaniard (left) is shown assisting an aboriginal laborer (right), although natives did nearly all the cultivating and harvesting work. Source: <http://www.mesolore.net/images/AGIMPyE70.jpg> (According to Donkin (1977), original painting located in Archivo General de Indias, Seville, Spain.)



Fig. 11a-b. Present-day harvesting of cochineal: a) Woman using an *isupu* and *asa* in her right and left hands, respectively; b) close-up view of *isupu* (top) and *asa* (bottom). (Both images by permission of Robin Smalley.)

Handprints Ltd. 2007). To conclude the unit and connect the two primary topics (silk and cochineal), students participate in a hands-on lab in which they dye silk fabric using dried cochineal insects and beeswax² for batikting. In the spirit of inquiry-based, experiential learning, we encourage students to conduct tests and record their findings with a variety of fabric swatches, mordants, and dye conditions. The basic process we developed involves five main steps, detailed below. Supplies and their sources are listed in Table 1. To reduce costs, we purchased stainless steel pans, potpourri pots, wooden spoons, etc., at second-hand stores. Useful references on mordanting and cochineal dyeing include Adrosko (1971), Kendal (2001), and Maiwa Handprints Ltd. (2007).

²Students learn about other uses of beeswax in a separate unit on apiculture and pollination.

Table 1. Laboratory materials for dyeing and batik.

Supply	Function
Step 1: Fabric Selection and Scouring	
Silk swatches and scarves	Fabric to dye
Muslin squares	Fabric to dye
Tags and safety pins	Mark fabric with students' names
Synthrapol SP ^{®1}	Scour fabric pre-mordanting and/or dyeing
Step 2: Mordanting	
Mordants ¹	Make dyed fabric colorfast
Top-loading balance	Weigh mordants
Large sauce pot (3 to 4 L)	Contain mordant bath and fabric
Electric burners	Heat pot with mordant solution
Pot holders	Hold hot objects
Step 3: Batiking	
Beeswax/paraffin	Serve as a dye resist
Potpourri pot	Melt wax
Tjanting tools and CJOPsticks ^{1,2}	Apply wax
Paintbrushes (Sumi) ¹	Apply wax
Embroidery hoops (4 in)	Hold fabric and facilitate batiking
Paper plates and paper towels	Place under fabric during batiking
Step 4: Dyeing with Cochineal	
Newspapers	Protect lab benches
Disposable gloves	Protect hands from dye
Dried cochineal insects ³	Dye fabric
Top-loading balance	Weigh cochineal insects
Mortar and pestle	Grind cochineal insects
Electric burners	Heat pot with dye bath
Large stainless steel pot (3 to 4 L)	Contain hot dye bath and fabric
Wooden cookware spoons	Stir dye bath
Cookware tongs	Move fabric out of hot bath
Step 5: Finishing the Product	
Synthrapol SP ^{®1}	Wash fabric after dyeing
Electric iron	Press finished product

¹Dharma Trading Co., San Rafael, CA

²Dick Blick Art Materials, Galesburg, IL

³Maiwa Handprints, Vancouver B.C.

Step 1: Fabric Selection and Scouring

Type and weight of silk strongly affect colors and hues obtained. Heavier silks, such as raw silk, retain wax more strongly during batiking and dye more intensely than lightweight silks. In addition to silk swatches, students are each given an inexpensive, lightweight Hobotai silk scarf (5 or 8 momme, 8" x 54"; Dharma Trading Co., San Rafael, CA), which they dye as a final project after experimenting on the smaller silk pieces. To remove imperceptible impurities (lubricants, dirt, oil, etc.) that may interfere with dye uptake, silk scarves are "scoured" by pre-washing in Synthrapol SP[®] detergent (Dharma Trading Co.) and air-dried prior to mordanting, batiking, and dyeing.

Step 2: Mordanting the Fabric

Mordants are substances that combine with a dye, making it more firmly fixed in the fabric and hence, more colorfast (i.e., resistant to fading and bleeding). Alum was used as a mordant for cochineal by pre-Colonial Mexicans, Mesoamericans, and South Americans (Donkin 1977). Most mordants are metallic salts or plant materials and each yields a different range of colors and hues after the fabric is dyed with cochineal (Adrosko 1971). We have had success with four mordants: stannous chloride, ferrous sulfate, tara (ground seed pods of *Caesalpinia spinosa*), and cream



Fig. 12a-b. Laboratory supplies: a) Two mordants (ferrous sulfate, left; and tara, center) impart a tawny shade to silk fabric before it is dyed with cochineal (right); b) equipment used to immerse fabric in mordant and dye baths (stainless steel pan, tongs, wooden spoon, pot holder) and to batik fabric (beeswax/paraffin mixture in electric potpourri pot, copper-tipped tjantings, and smaller CJOPsticks).

of tartar (potassium bitartrate) plus alum (potassium aluminum sulfate) (Fig. 12a).

Mordanting procedure

Note: As a safety precaution, instructors may wish to have students wear gloves when handling mordant solutions.

1. Place 2 L water in a large saucepan.
2. Add desired amount of mordant (Table 2) and stir until dissolved.
3. Heat to boiling, then reduce heat to simmer.
4. Add 45-55 g fabric (e.g., four or five 8" x 54" Hobotai silk scarves).
5. Simmer 30 min, stirring frequently.
6. Remove fabric from bath, rinse in cold water, hang to dry.

Step 3: Batiking with Beeswax and Tjanting Tools

Batiking is the process of producing patterns in textiles by applying hot wax to fabric, dyeing the exposed area, and removing the wax. Tjantings are hand-held metal tools used to apply liquid wax to fabric to create a pattern. We prefer tjantings made with copper (Fig.



Fig. 13a-d. Procedural steps for batik and dyeing: a) student batiks a fabric swatch by applying melted beeswax/paraffin using a tjanting tool; b) students grind dried cochineal insects to a powder using a mortar and pestle; c) students simmer ground cochineal powder in hot water and stir with wooden spoon to produce dye bath; d) after mordanting, batiking, and dyeing, silk is washed in Synthrapol SP® (Dharma Trading Co.) and ironed to remove wrinkles.

12b), as they retain heat longer than those featuring other metals and so facilitate wax application. Students experiment with tjantings on swatches of fabric before they attempt to batik their silk scarves. They may opt to apply wax with Sumi brushes (Dharma Trading Co.) or create geometric and animal shapes with CJOPstiks (Dick Blick Art Materials, Galesburg, IL; Fig. 12b).

Batiking procedure

1. Prepare a 1:1 (w/w) mixture of paraffin and beeswax, and melt in an electric potpourri pot. (We have also used a 3:1 ratio of paraffin:beeswax. This ratio produces patterns with fine lines in the finished batik, as paraffin cracks more easily than beeswax, and cochineal enters these cracks during the dyeing step.)
2. Stretch fabric on an embroidery hoop. If desired, draw a pattern in pencil.
3. Dip tjanting into hot wax to fill.
4. Remove tjanting from potpourri pot and apply to fabric in one continuous motion (Fig. 13a). Pausing or stopping causes the wax to pool on the fabric.
5. Repeat steps 3 and 4 until wax application is complete.
6. Allow the batik to cool.

Step 4: Dyeing with Cochineal

Dye concentration and duration of dyeing affect the color and shade produced (Table 2). The procedure below yields medium to dark colors; use less cochineal or shorter durations for paler shades. If wax was applied, cool the dye bath to prevent wax from melting out of the fabric too quickly, particularly from lightweight silk fabrics (e.g., Habotai). String may be used to create tie-dyed patterns in the fabric.

Dyeing procedure

Note: As a safety precaution, instructors may wish to have students wear gloves when handling cochineal dye baths. Procedure below is suitable for 50 g fabric (ca. five Habotai silk scarves).

1. Weigh 10 g dried cochineal insects.
2. Grind to a fine powder with mortar and pestle (Fig. 13b).
3. Add to 3 L water in stainless steel pot and stir.
4. Heat to boiling. Boil 30 min to extract dye and stir occasionally (Fig. 13c). Cool dye bath if wax was applied to fabric.
5. Add fabric for desired time and stir frequently.
6. Remove fabric from bath and rinse in cold water until water runs clear.

Step 5: Finishing the Product

1. Wash fabric in Synthrapol SP® (Dharma Trading Co.) to remove loose particles of cochineal and to prevent lighter colored areas from becoming “muddy” due to excess dye (Fig. 13d); hang to dry.
2. Press finished product with an electric iron. *Note: To remove residual wax from batiked material, place fabric between layers of newsprint and paper towels and press. Repeat using fresh paper towels until all wax is removed.*

DISCUSSION

Using methods described herein, students successfully made an artistic assortment of cochineal-dyed, beeswax-batiked silk swatches and scarves (Figs. 13d, 14a-d). In the absence of mordant, red hues (pale pink to raspberry rose) were produced, but mordanting with stannous chloride yielded more intensely colored fabrics (Thulian pink, red-violet, and crimson) (Table 2). A vibrant scarlet color was achieved with stannous chloride as a mordant, relatively con-

Table 2. Details for various mordant and dye solutions, with final fabric colors obtained.

Mordant ¹ / water	Cochineal ² / water	Notes ³	Color spectrum or color ⁴
No mordant	9 g, 23 g, <u>or</u> 46 g/L	10, 20, 30, or 40 min in cochineal dye bath @ low simmer	Pale Pink to Tea Rose to Raspberry Rose
No mordant	46g/L	15 min in cochineal dye @ 25° C	Grey
Stannous chloride 1 g / L	9 g, 23 g, <u>or</u> 46 g/L	30 min in cochineal dye bath @ low simmer	Rose to shades of Red-Violet
Stannous chloride 1 g/L	92 g/L	50 min in cochineal dye bath @ low simmer	Scarlet
Stannous chloride 2 g/L	50 g <u>or</u> 75 g/L	30 min in mordant @ low simmer, 5 min in cochineal dye bath @ low simmer	Red to Crimson
Stannous chloride 2 g/L	10 g/L	30 min in mordant low simmer, 1 or 2 min cochineal dye bath @ low simmer	Thulian Pink or Red-Violet
Stannous chloride 2 g/L	10 g/L	30 min in mordant @ low simmer, 40 min cochineal dye bath @ 25° C	Rose
Ferrous sulfate 1 g/L	15 g <u>or</u> 30 g/3L	10 or 30 min in cochineal dye bath @ low simmer	Blue to Royal Purple
Tara 7 g/L	9 g, 23 g, <u>or</u> 46 g/L	30 min in cochineal dye bath @ low simmer	Old Rose to Terracotta to Rose Taupe
Cream of tartar/alum 10 g each/L	9 g, 23 g, 46 g, <u>or</u> 92 g/L	30, 40, or 50 min in cochineal dye bath @ low simmer	Pale Thulian Pink to Mauve Taupe to Cordovan

¹Concentrations tested; different mordant concentrations yield different final colors.

²Concentrations tested; lower dye concentrations yield paler shades in the color spectrum.

³For batiked Habotai silk: reduce time in simmering dye bath to ≤ 2 min, or dye in cooler bath temperatures for longer times, as wax may melt out and patterns become changed or lost.

⁴Colors spectrum yielded, from least to most concentrated dye baths, using lightweight Habotai silk. To view colors listed, search color names at: <http://en.wikipedia.org/wiki/>



Fig. 14a-d. Students' results: a) range of colors and hues obtained with swatches of fabrics tested using various mordant and cochineal concentrations and combinations, and durations of mordanting/dyeing; b) scarlet batiked Habotai silk headbands produced using a stannous chloride mordant and a concentrated dye preparation; c) posing proudly with cochineal-dyed Habotai silk scarves mordanted with stannous chloride (left) or ferrous sulfate (right); and d) array of colors, hues, and patterns obtained with cochineal-dyed Habotai silk scarves; patterns obtained by tie-dyeing (i.e., folding fabric and securing tightly with string before immersion in mordant and dye baths).

concentrated dye baths (46-92 g cochineal/L) that had cooled to room temperature, and a dye bath duration of only 5 minutes (Fig. 14b). Students created fabrics of blue and purple hues using ferrous sulfate as a mordant, and produced different shades of purplish brown using tara or cream of tartar plus alum as mordants (Table 2). One student produced an orange Hobotai silk scarf, and although he did not record the dye concentration or mordants used, he most likely used both stannous chloride and cream of tartar, as the latter is acidic and cochineal is extremely sensitive to pH shifts, yielding orange-red in acidic dye baths (Maiwa Handprints Ltd. 2007).

To generate student feedback on the lab activities for this unit, in 2005 we distributed an anonymous questionnaire that included the open-ended query, "What did you like about these labs, and why?" The following responses were typical and suggested that students enjoyed opportunities to work creatively and independently: 1) "Best lab, most fun, most involved"; 2) "Liked everything – fun, involving, and creative"; 3) "Freedom to experiment, something I've never done"; 4) "Very hands-on"; 5) "Enjoyed overall process of creating a dye and using it."

Our questionnaire also included prompts that asked students to rate various Silk Road activities on a Likert scale of 1 to 5 (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). Students ($n = 15$, all non-majors) indicated that they learned new information about the history of silk (4.53 ± 0.64), had a better appreciation of the silk routes and their impact on many aspects of human history and civilization (4.47 ± 0.83), enjoyed the "Web of Knowledge" activity (4.40 ± 0.83), learned new information about the history of cochineal dye (4.73 ± 0.46), and enjoyed using cochineal to dye silk (4.50 ± 0.76).

Based on these results, and responses to the silk/cochineal/batik unit in other years, we believe that inquiry-based, experiential learning, coupled with an interdisciplinary pedagogy, helps students to learn effectively. As instructors, we enjoyed developing this unit and are gratified teaching it, and hope others will find our approaches beneficial.

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