

TEXTILE SCIENCE & CLOTHING CONSTRUCTION

A high-school year in the science and craft of cloth: where every fiber comes from and what its molecules do, how yarns are spun and fabrics woven, knitted and finished, how the sewing machine forms a stitch, and how a pattern is fitted and a real garment built, with the lab tests, yardage math and construction logs of a working textile lab and tailor's shop.

This course is a year of textile science and clothing construction for high-school students. The first half is the science of cloth: plant fibers built from cellulose, animal fibers built from the proteins keratin and fibroin, and the regenerated and synthetic fibers made by chemists, from Chardonnet's rayon to Carothers's nylon and Shivers's spandex; then yarns (twist, ply and the count systems of the trade), fabrics (woven, knitted, felted and lace), and the dyes, prints and finishes that make cloth useful and the care labels that keep it that way. The second half is construction: the sewing machine and the serger and how each forms its stitch, seams and seam strength, pressing, patterns and fit, darts, casings, zippers, collars, sleeves, buttonholes and hems, and finally tailoring, alteration, mending and a capstone garment the student designs, fits and builds.

Every lesson follows the same path. First comes **the story**: Eli Whitney's gin and the history it changed, John Mercer's caustic bath, Gideon's fleece wrung out in the morning, the silkworm eggs carried to Constantinople, Samuel Slater's mill, Jacquard's punched cards, William Perkin's purple, Elias Howe's needle and Ebenezer Butterick's tissue patterns. Then **how they figured it out**: the problem, the trials, the result. Then **the fabric science and the math**: polymer chains and hydrogen bonds, moisture regain, denier and tex, thread count and fabric weight, shrinkage and seam strength, ease, yardage and grading, worked step by step with units in every line. Last, **the studio lab**: a real fabric test with a question, a hypothesis, controlled variables and a data table, or a real piece of sewing with a pattern card, a standard to meet and a repeat round. Unit tests, a midterm and a final check both the ideas and the arithmetic.

Sewing here is skill, stewardship and service: understanding the materials God made and the ones people learned to make, choosing cloth wisely, caring for clothes and mending them instead of throwing them away, and making things for others. Scripture is full of this work, from the coats of skins in Eden and the fine twined linen of the tabernacle to the capable woman who seeks wool and flax, Hannah's little coat made new every year, and Christ's coat woven without seam from the top throughout. *Fabricando fit faber*: by making, one becomes a maker.

Who it is for: Written for students in grades 9–12 working mostly on their own, with a parent checking work and present in the house for iron, serger, rotary-cutter, burn-test and dye work. There is no prerequisite course, though a K–8 sewing course helps; Unit 7 teaches the machine from the beginning, and Units 1–6 need only hand sewing. The math is Algebra I: percents, ratios, unit conversions and simple formulas, with a calculator allowed everywhere. To begin, the student needs a working sewing machine (borrowed is fine), a steam iron and board, fabric shears and snips, a seam ripper, pins and clips, a 60-inch tape measure and a clear quilting ruler, a rotary cutter and mat, a hand-sewing kit, a lab notebook and a calculator, and for the science units a 10× magnifier or linen tester, a kitchen scale reading grams, tweezers or hemostats and a metal pan.

50 lessons in 10 units · Every lesson has a video (links printed in each lesson), a picture study, a studio lab and notebook practice · Online: schoollaunch.org/courses/sewing/textile-science/

COURSE GUIDE

Most videos come from trusted teaching sources: museums and historic sites (the Smithsonian, the Victoria and Albert Museum, Colonial Williamsburg, Mount Vernon, national and state historical parks), university and extension programs, official How It's Made uploads, fiber councils filmed in the field and the mill, the education channels of sewing-machine makers, and careful sewing and tailoring teachers chosen lesson by lesson. Every video was previewed for content, accuracy, safe practice and modest dress. A few channels sell fabric, thread or patterns and mention their shop at the end; the teaching stands on its own, and you can stop the video when the lesson ends. Many lessons ask you to watch once through, then again with the fabric, tape measure or machine in front of you, pausing after each step.

HOW TO USE THIS COURSE

1. **The weekly rhythm.** The course runs five sessions a week of about 50 minutes. Each lesson takes three sessions: (1) the warm-up, video, teaching, picture study and worked examples; (2) the studio lab and the lab notebook; (3) the practice set and corrections. After each unit comes a unit test worth 100 points, with a review day and the midterm after Unit 5 and a review day and the final at the end of the year. Sewing labs in Units 7–10 often run 60–90 minutes; let them spill into an evening rather than rush a seam.
2. **Work like a lab and a workroom.** Science labs begin with a question and a written hypothesis, change one variable at a time, record every measurement with its unit in a data table, and end with a conclusion the data actually support. Sewing labs begin with measurements, a pattern card and a cutting plan, and end with the piece checked against a written standard and one honest note about what to change. That habit, not perfection, is what the course grades.
3. **Safety and the parent check.** A student in this course may use the sewing machine, serger, steam iron and rotary cutter alone **only after a parent has watched him or her use each one safely**, and with a parent at home. Pins and needles are counted out and back in every session and kept in a pincushion or magnetic dish, away from babies, toddlers and pets. The rotary cutter's blade is closed every time it is set down. Irons rest upright and are never left on unattended; machines are unplugged before changing needles, blades or threading the serger.
4. **Burn tests and chemicals.** Fiber burn tests are done **with a parent beside the student**: a ½-inch snippet held in tweezers or hemostats over a metal pan or sink, water at hand, hair tied back, sleeves pushed up, and synthetics kept well away from the face because they melt and drip. Dyeing is done with gloves, ventilation and a parent present, following the dye maker's directions, never in a pot used for food. Chlorine bleach is never mixed with anything. Lye (caustic soda) and other strong chemicals in the history lessons are described, not used at home.
5. **Modesty and measuring.** Every garment made in this course is modest and practical: pajama pants, skirts, vests, shirts, aprons and the like. Body measurements are taken over light clothing by a parent (for older students, the father for a son or the mother for a daughter), and are written down for fit only. They are never discussed as good or bad numbers, and bodies are never compared. Fit is about comfort, ease of movement, durability and suiting the occasion.
6. **The story-to-science pattern.** The core ideas open with a real story and end with the lab. Read them with a pencil: the worked examples are meant to be re-worked by hand, units and all, before you start the practice set.
7. **Picture study.** Each lesson pairs with one public-domain painting, photograph, patent drawing or engraving. Look at it quietly for two minutes, put it away and describe it from memory, then work through the look-for items and questions, which point at the fiber, the cloth, the tools and the hands.
8. **The lab notebook.** One notebook for the year. Every lab gets a dated page: the question and hypothesis, the data table, taped-in swatches, sketches through the magnifier, the math, the conclusion and a one-line improvement note. Sewing labs add the pattern card, the cutting plan and a cost line. The notebook is a tenth of the grade and becomes the construction log for the capstone.
9. **Supplies and cost.** The labs use ordinary fabric-store supplies, kitchen tools, thrift-store garments and the family's own closet and rag bag. Old sheets make excellent muslins; old shirts and jeans are free test fabric. A sewing machine is required from Unit 7 on; a serger is never required. Read each unit project before the unit begins so supplies can be gathered ahead.

10. **Make it a game.** Every lesson ends with a short family game or timed challenge built on the lesson's skill: an identification race, an estimation duel, a blind feel-test. Play it at dinner; it is the cheapest review there is.
11. **Optional books and tools.** Some units list free extension guides, standards pages and simple tools. They are extras; every lab works without them.
12. **Unit tests and exams.** Unit tests mix calculations, concepts, identification and one short essay, worth 100 points; calculators are allowed, and every calculation shows the formula, the substitution with units and the answer with its unit. The midterm covers Units 1–5 and the final covers the year.
13. **The capstone.** Unit 10 ends with a capstone garment the student designs, fits in muslin and builds, with a construction log and a full cost analysis. Begin thinking about it at the midterm; the pattern drafted in Unit 8 and the skills of Unit 9 feed straight into it.

SCOPE AND SEQUENCE

UNIT 1 • WEEKS 1–4

Fibers from Plants

Cellulose and the plant fibers: cotton from boll to bale, Whitney's gin and the history it changed, the structure of the cotton fiber, Mercer's mercerization, flax and linen, hemp, jute and ramie, and a burn-and-feel identification lab.

- 1.1 King Cotton: The Boll, the Gin and the Honest History
- 1.2 Cellulose Under the Lens
- 1.3 John Mercer's Caustic Bath
- 1.4 Flax and Fine Linen
- 1.5 Hemp, Jute, Ramie and the Burn-and-Feel Lab

UNIT 3 • WEEKS 7–10

Manufactured Fibers

Fibers made by people, stated fairly: rayon and lyocell from wood, nylon 6,6, polyester and acrylic, spandex and stretch, wet, dry and melt spinning, filament and staple, microfibers and blends, with a moisture-regain and drying-time lab.

- 3.1 Chardonnet's Silk and the Viscose Process
- 3.2 Carothers and Nylon 6,6
- 3.3 Polyester, Acrylic and the Spinneret
- 3.4 Shivers's Spandex and the Science of Stretch
- 3.5 Microfibers, Blends and the Fair Verdict

UNIT 5 • WEEKS 13–17

Fabric Construction

Fabric construction: plain, twill and satin weaves, Jacquard's cards and the truth about thread count, fabric weight, weft and warp knits from William Lee's frame on, nonwovens, felt and lace, with a fabric-analysis lab under the linen tester.

- 5.1 The Loom: Warp, Weft and Plain Weave
- 5.2 Twill, Satin and Fabric Analysis
- 5.3 Jacquard's Cards and the Truth About Thread Count
- 5.4 William Lee's Frame and the Knit Loop
- 5.5 Felt, Nonwovens and Lace

UNIT 2 • WEEKS 4–7

Fibers from Animals

The protein fibers: keratin and wool's scales, crimp and lanolin, moisture and Gideon's fleece, shearing and micron counts, felting and shrinkage, the specialty hair fibers, and silk from the silkworm to the Silk Road.

- 2.1 Keratin and Gideon's Fleece
- 2.2 From Shearing Shed to Micron Count
- 2.3 Felting and Shrinkage: Wool's Scales at Work
- 2.4 Mohair, Cashmere, Alpaca and Camel
- 2.5 Silk: Fibroin, the Silkworm and the Silk Road

UNIT 4 • WEEKS 10–13

Yarns

Yarns: the spindle, the wheel and the inventions of Hargreaves, Arkwright and Crompton, Slater and the Lowell mills told plainly, twist and ply, denier, tex and cotton count, novelty yarns and sewing thread, with a twist-and-strength lab.

- 4.1 The Spindle and the Wheel
- 4.2 Hargreaves, Arkwright and Crompton
- 4.3 Slater, Lowell and the Mill
- 4.4 Yarn Count: Denier, Tex and Cotton Count
- 4.5 Ply, Novelty Yarns and Sewing Thread

UNIT 6 • WEEKS 17–20

Finishes, Color and Care

Color, finishes and care: natural dyes and mordants, Perkin's mauve and the dye classes, block, roller and screen printing, Sanforizing, permanent press, water repellency and flame resistance, the Triangle Shirtwaist fire as fire-safety history, the FTC care and fiber-content rules, and stain chemistry.

- 6.1 Madder, Indigo and Lydia's Purple
- 6.2 Perkin's Mauve and the Dye Chemist's Toolbox
- 6.3 Printing Cloth: Blocks, Rollers and Screens
- 6.4 Finishes: Sanforizing, Permanent Press and Fire Safety
- 6.5 Care Labels and the Chemistry of Stains

UNIT 7 • WEEKS 20–23

Tools, the Machine and the Serger

The machine: Hunt, Howe and Singer and the patent pool of 1856, how a lockstitch forms, needles, thread and tension, seam types and a seam-strength lab, Merrow's overlock and the serger, and the physics of pressing.

- 7.1 Hunt, Howe and the Eye-Pointed Needle
- 7.2 Singer, the Combination and the Lockstitch
- 7.3 Seams and Seam Strength
- 7.4 Merrow's Overlock and the Serger
- 7.5 Pressing: Heat, Moisture and Pressure

UNIT 9 • WEEKS 27–30

Garment Construction

Garment construction: darts, casings and elastic, zippers from Judson to Sundback, facings, collars and set-in sleeves, buttonholes, buttons and hems, building pajama pants and then a lined vest or button-front shirt.

- 9.1 Darts: Making Flat Cloth Round
- 9.2 Casings, Elastic and Pajama Pants
- 9.3 Judson, Sundback and the Zipper
- 9.4 Facings, Collars and Sleeves
- 9.5 Buttonholes, Buttons and Hems

UNIT 8 • WEEKS 23–26

Patterns and Fit

Patterns and fit: Butterick's graded tissue pattern, modest body measurement for fit only, wearing and design ease, pattern symbols, grain and layout yardage, a fitted muslin, and drafting and grading a simple pattern.

- 8.1 Butterick's Graded Pattern
- 8.2 Measuring and Ease
- 8.3 Grain, Symbols and Layout
- 8.4 The Muslin and the Fitting
- 8.5 Drafting and Grading: Hannah's Coat Every Year

UNIT 10 • WEEKS 30–33

Tailoring, Alteration and the Capstone Garment

The tailor's craft: interfacing, hair canvas and pad stitching, altering store-bought clothes, mending, care and cost per wear, and a capstone garment designed, fitted and built with a full construction log and cost analysis.

- 10.1 The Tailor's Craft: Canvas and Pad Stitching
- 10.2 Altering Store-Bought Clothes
- 10.3 Mending: Dorcas and the Coats She Made
- 10.4 Care, Cost per Wear and Make or Buy
- 10.5 The Capstone Garment

WEEKLY PACING CALENDAR

WEEK	PLAN
1	- Day 1: Lesson 1.1 King Cotton: The Boll, the Gin and the Honest History: video, teaching and worked examples - Day 2: Lesson 1.1: studio lab and notebook - Day 3: Lesson 1.1: practice set and corrections - Day 4: Lesson 1.2 Cellulose Under the Lens: video, teaching and worked examples - Day 5: Lesson 1.2: studio lab and notebook <i>Five sessions a week of about 50 minutes. Families on a four-day week can combine the practice day of one lesson with the teaching day of the next.</i>
2	- Day 1: Lesson 1.2: practice set and corrections - Day 2: Lesson 1.3 John Mercer's Caustic Bath: video, teaching and worked examples - Day 3: Lesson 1.3: studio lab and notebook - Day 4: Lesson 1.3: practice set and corrections - Day 5: Lesson 1.4 Flax and Fine Linen: video, teaching and worked examples
3	- Day 1: Lesson 1.4: studio lab and notebook - Day 2: Lesson 1.4: practice set and corrections - Day 3: Lesson 1.5 Hemp, Jute, Ramie and the Burn-and-Feel Lab: video, teaching and worked examples - Day 4: Lesson 1.5: studio lab and notebook - Day 5: Lesson 1.5: practice set and corrections
4	- Day 1: Unit 1 test - Day 2: Lesson 2.1 Keratin and Gideon's Fleece: video, teaching and worked examples - Day 3: Lesson 2.1: studio lab and notebook - Day 4: Lesson 2.1: practice set and corrections - Day 5: Lesson 2.2 From Shearing Shed to Micron Count: video, teaching and worked examples
5	- Day 1: Lesson 2.2: studio lab and notebook - Day 2: Lesson 2.2: practice set and corrections - Day 3: Lesson 2.3 Felting and Shrinkage: Wool's Scales at Work: video, teaching and worked examples

WEEK	PLAN
	- Day 4: Lesson 2.3: studio lab and notebook - Day 5: Lesson 2.3: practice set and corrections
6	- Day 1: Lesson 2.4 Mohair, Cashmere, Alpaca and Camel: video, teaching and worked examples - Day 2: Lesson 2.4: studio lab and notebook - Day 3: Lesson 2.4: practice set and corrections - Day 4: Lesson 2.5 Silk: Fibroin, the Silkworm and the Silk Road: video, teaching and worked examples - Day 5: Lesson 2.5: studio lab and notebook
7	- Day 1: Lesson 2.5: practice set and corrections - Day 2: Unit 2 test - Day 3: Lesson 3.1 Chardonnet's Silk and the Viscose Process: video, teaching and worked examples - Day 4: Lesson 3.1: studio lab and notebook - Day 5: Lesson 3.1: practice set and corrections
8	- Day 1: Lesson 3.2 Carothers and Nylon 6,6: video, teaching and worked examples - Day 2: Lesson 3.2: studio lab and notebook - Day 3: Lesson 3.2: practice set and corrections - Day 4: Lesson 3.3 Polyester, Acrylic and the Spinneret: video, teaching and worked examples - Day 5: Lesson 3.3: studio lab and notebook
9	- Day 1: Lesson 3.3: practice set and corrections - Day 2: Lesson 3.4 Shivers's Spandex and the Science of Stretch: video, teaching and worked examples - Day 3: Lesson 3.4: studio lab and notebook - Day 4: Lesson 3.4: practice set and corrections - Day 5: Lesson 3.5 Microfibers, Blends and the Fair Verdict: video, teaching and worked examples
10	- Day 1: Lesson 3.5: studio lab and notebook - Day 2: Lesson 3.5: practice set and corrections - Day 3: Unit 3 test - Day 4: Lesson 4.1 The Spindle and the Wheel: video, teaching and worked examples - Day 5: Lesson 4.1: studio lab and notebook
11	- Day 1: Lesson 4.1: practice set and corrections - Day 2: Lesson 4.2 Hargreaves, Arkwright and Crompton: video, teaching and worked examples - Day 3: Lesson 4.2: studio lab and notebook - Day 4: Lesson 4.2: practice set and corrections - Day 5: Lesson 4.3 Slater, Lowell and the Mill: video, teaching and worked examples
12	- Day 1: Lesson 4.3: studio lab and notebook - Day 2: Lesson 4.3: practice set and corrections - Day 3: Lesson 4.4 Yarn Count: Denier, Tex and Cotton Count: video, teaching and worked examples - Day 4: Lesson 4.4: studio lab and notebook - Day 5: Lesson 4.4: practice set and corrections
13	- Day 1: Lesson 4.5 Ply, Novelty Yarns and Sewing Thread: video, teaching and worked examples - Day 2: Lesson 4.5: studio lab and notebook - Day 3: Lesson 4.5: practice set and corrections - Day 4: Unit 4 test - Day 5: Lesson 5.1 The Loom: Warp, Weft and Plain Weave: video, teaching and worked examples
14	- Day 1: Lesson 5.1: studio lab and notebook - Day 2: Lesson 5.1: practice set and corrections - Day 3: Lesson 5.2 Twill, Satin and Fabric Analysis: video, teaching and worked examples - Day 4: Lesson 5.2: studio lab and notebook - Day 5: Lesson 5.2: practice set and corrections
15	- Day 1: Lesson 5.3 Jacquard's Cards and the Truth About Thread Count: video, teaching and worked examples - Day 2: Lesson 5.3: studio lab and notebook

WEEK	PLAN
	- Day 3: Lesson 5.3: practice set and corrections - Day 4: Lesson 5.4 William Lee's Frame and the Knit Loop: video, teaching and worked examples - Day 5: Lesson 5.4: studio lab and notebook
16	- Day 1: Lesson 5.4: practice set and corrections - Day 2: Lesson 5.5 Felt, Nonwovens and Lace: video, teaching and worked examples - Day 3: Lesson 5.5: studio lab and notebook - Day 4: Lesson 5.5: practice set and corrections - Day 5: Unit 5 test
17	- Day 1: Review day for the midterm - Day 2: Midterm exam - Day 3: Lesson 6.1 Madder, Indigo and Lydia's Purple: video, teaching and worked examples - Day 4: Lesson 6.1: studio lab and notebook - Day 5: Lesson 6.1: practice set and corrections
18	- Day 1: Lesson 6.2 Perkin's Mauve and the Dye Chemist's Toolbox: video, teaching and worked examples - Day 2: Lesson 6.2: studio lab and notebook - Day 3: Lesson 6.2: practice set and corrections - Day 4: Lesson 6.3 Printing Cloth: Blocks, Rollers and Screens: video, teaching and worked examples - Day 5: Lesson 6.3: studio lab and notebook
19	- Day 1: Lesson 6.3: practice set and corrections - Day 2: Lesson 6.4 Finishes: Sanforizing, Permanent Press and Fire Safety: video, teaching and worked examples - Day 3: Lesson 6.4: studio lab and notebook - Day 4: Lesson 6.4: practice set and corrections - Day 5: Lesson 6.5 Care Labels and the Chemistry of Stains: video, teaching and worked examples
20	- Day 1: Lesson 6.5: studio lab and notebook - Day 2: Lesson 6.5: practice set and corrections - Day 3: Unit 6 test - Day 4: Lesson 7.1 Hunt, Howe and the Eye-Pointed Needle: video, teaching and worked examples - Day 5: Lesson 7.1: studio lab and notebook
21	- Day 1: Lesson 7.1: practice set and corrections - Day 2: Lesson 7.2 Singer, the Combination and the Lockstitch: video, teaching and worked examples - Day 3: Lesson 7.2: studio lab and notebook - Day 4: Lesson 7.2: practice set and corrections - Day 5: Lesson 7.3 Seams and Seam Strength: video, teaching and worked examples
22	- Day 1: Lesson 7.3: studio lab and notebook - Day 2: Lesson 7.3: practice set and corrections - Day 3: Lesson 7.4 Merrow's Overlock and the Serger: video, teaching and worked examples - Day 4: Lesson 7.4: studio lab and notebook - Day 5: Lesson 7.4: practice set and corrections
23	- Day 1: Lesson 7.5 Pressing: Heat, Moisture and Pressure: video, teaching and worked examples - Day 2: Lesson 7.5: studio lab and notebook - Day 3: Lesson 7.5: practice set and corrections - Day 4: Unit 7 test - Day 5: Lesson 8.1 Butterick's Graded Pattern: video, teaching and worked examples
24	- Day 1: Lesson 8.1: studio lab and notebook - Day 2: Lesson 8.1: practice set and corrections - Day 3: Lesson 8.2 Measuring and Ease: video, teaching and worked examples - Day 4: Lesson 8.2: studio lab and notebook - Day 5: Lesson 8.2: practice set and corrections

WEEK	PLAN
25	- Day 1: Lesson 8.3 Grain, Symbols and Layout: video, teaching and worked examples - Day 2: Lesson 8.3: studio lab and notebook - Day 3: Lesson 8.3: practice set and corrections - Day 4: Lesson 8.4 The Muslin and the Fitting: video, teaching and worked examples - Day 5: Lesson 8.4: studio lab and notebook
26	- Day 1: Lesson 8.4: practice set and corrections - Day 2: Lesson 8.5 Drafting and Grading: Hannah's Coat Every Year: video, teaching and worked examples - Day 3: Lesson 8.5: studio lab and notebook - Day 4: Lesson 8.5: practice set and corrections - Day 5: Unit 8 test
27	- Day 1: Lesson 9.1 Darts: Making Flat Cloth Round: video, teaching and worked examples - Day 2: Lesson 9.1: studio lab and notebook - Day 3: Lesson 9.1: practice set and corrections - Day 4: Lesson 9.2 Casings, Elastic and Pajama Pants: video, teaching and worked examples - Day 5: Lesson 9.2: studio lab and notebook
28	- Day 1: Lesson 9.2: practice set and corrections - Day 2: Lesson 9.3 Judson, Sundback and the Zipper: video, teaching and worked examples - Day 3: Lesson 9.3: studio lab and notebook - Day 4: Lesson 9.3: practice set and corrections - Day 5: Lesson 9.4 Facings, Collars and Sleeves: video, teaching and worked examples
29	- Day 1: Lesson 9.4: studio lab and notebook - Day 2: Lesson 9.4: practice set and corrections - Day 3: Lesson 9.5 Buttonholes, Buttons and Hems: video, teaching and worked examples - Day 4: Lesson 9.5: studio lab and notebook - Day 5: Lesson 9.5: practice set and corrections
30	- Day 1: Unit 9 test - Day 2: Lesson 10.1 The Tailor's Craft: Canvas and Pad Stitching: video, teaching and worked examples - Day 3: Lesson 10.1: studio lab and notebook - Day 4: Lesson 10.1: practice set and corrections - Day 5: Lesson 10.2 Altering Store-Bought Clothes: video, teaching and worked examples
31	- Day 1: Lesson 10.2: studio lab and notebook - Day 2: Lesson 10.2: practice set and corrections - Day 3: Lesson 10.3 Mending: Dorcas and the Coats She Made: video, teaching and worked examples - Day 4: Lesson 10.3: studio lab and notebook - Day 5: Lesson 10.3: practice set and corrections
32	- Day 1: Lesson 10.4 Care, Cost per Wear and Make or Buy: video, teaching and worked examples - Day 2: Lesson 10.4: studio lab and notebook - Day 3: Lesson 10.4: practice set and corrections - Day 4: Lesson 10.5 The Capstone Garment: video, teaching and worked examples - Day 5: Lesson 10.5: studio lab and notebook
33	- Day 1: Lesson 10.5: practice set and corrections - Day 2: Unit 10 test - Day 3: Review day for the final - Day 4: Final exam

MATERIALS

A sewing machine in working order (required from Unit 7)

Any home machine with a straight stitch, a zigzag and a buttonhole stitch, plus its manual, a zipper foot, spare universal, ballpoint and denim needles, and bobbins that fit it. Borrowing from a relative or a friend at church is fine. A serger is a helpful extra, never required.

A steam iron, ironing board and pressing tools

A press cloth (a plain cotton dish towel works), and if possible a tailor's ham and a seam roll. A rolled towel stands in for both. A wooden clapper is easy to make from a smooth hardwood block.

Cutting tools

Fabric shears, small thread snips, a seam ripper, and a rotary cutter with a self-healing mat and a clear 6 × 24 inch quilting ruler. The rotary blade is closed every time it is set down.

Measuring and marking

A 60-inch tape measure, a clear ruler, a yardstick, tailor's chalk or a washable marker, and a French curve or flexible ruler for pattern work in Units 8–10.

A hand-sewing kit and pins

Sharps and embroidery needles, a thimble, all-purpose polyester and cotton thread, dressmaker pins, sewing clips, and a pincushion or magnetic dish for the needle-and-pin count.

Science-lab tools (Units 1–6)

A 10× magnifier or linen tester (thread counter), a kitchen scale reading to 1 gram (0.1 gram is better), tweezers or hemostats, a metal pan or baking sheet for burn tests, a kitchen or candy thermometer, a timer, a small bucket and a supply of coins, washers or water bottles as test weights, zip-top bags and masking tape for labels.

Fabric, fiber and yarn

A labeled stash of swatches from the rag bag and thrift store (cotton, linen, wool, silk, rayon, nylon, polyester, acrylic and blends), a few ounces of wool roving and cotton balls, cotton and wool yarn, unbleached muslin or old flat sheets for muslins, and garment fabric chosen for each Unit 9 and 10 project.

A lab notebook, glue stick, calculator and camera or phone

The notebook holds data tables, taped-in swatches, magnifier sketches, pattern cards, cost sheets and the capstone construction log.

GRADING

Grades reward the habits of a good lab and a good tailor's shop: measure honestly, change one thing at a time, record everything, and finish. A lab whose first seam was crooked, honestly recorded, unpicked and sewn again earns full credit; a test calculation earns its points by showing the formula, the substitution with units and the answer with its unit.

PART	%
Practice sets (completed and corrected)	15
Studio labs (safety, technique, measurement, honest records)	25
Lab notebook (data tables, swatches, math, pattern cards, improvement notes)	10
Unit tests	30
Midterm exam (Units 1–5)	10
Final exam (Units 1–10)	10

Scale: A 90–100, B 80–89, C 70–79, D 60–69. Below 60: rework the unit's labs and retake the test after review.

- Labs are graded on safety, technique, measurement and honest records, not on whether the result was perfect or the hypothesis was right. A hypothesis the data overturn, honestly reported, is good science.

- Safety is pass or fail for any lab: parent beside you for burn tests and dyeing, pins counted in and out, rotary blade closed, iron upright and unplugged at the end, machine unplugged before changing a needle. An unsafe shortcut redoes the lab.
- Show work on every calculation: formula, substitution with units, answer with its unit. Right answers with no work earn half credit on tests.
- Body measurements in Units 8–10 are taken over light clothing, by a parent (the father for a son or the mother for a daughter), and recorded for fit only. They are never discussed as good or bad numbers, and bodies are never compared.
- The capstone garment is graded on its own rubric in Unit 10: design and pattern, fit, workmanship, construction log and cost analysis.

A NOTE TO PARENTS

You do not need to be a chemist or a tailor to run this course. Your work is to check the lab notebook weekly, stand beside the student for every burn test and dye bath, watch the student run each new tool once before signing it off, be in the house during tool work, and ask the lab questions: What did you change? What stayed the same? What do the numbers say? What would you do differently? The course is written to the student and the videos show the techniques; your judgment carries the safety rules.

The science units turn the house into a small textile lab: swatches drying on a rack, strips hanging from a bucket of coins, a felted sweater shrinking in the washer on purpose. Let it happen. A thrift-store wool sweater, an old cotton sheet and a polyester shirt are cheap tuition, and the closet survey and stain lab teach a lifetime of good laundry habits. The construction units then turn those materials into clothing the student actually wears: pajama pants, a vest or shirt, real alterations and mending for the family, and a capstone garment.

Two history stories need a parent's frame. The cotton gin made cotton cheap and, sadly, made slavery in the American South grow; and the mills of the 1800s, from Lowell to the Carolinas, employed children and young women for long hours, a history the course tells plainly, along with how laws and fire codes changed after the Triangle Shirtwaist fire of 1911. The course tells these things honestly and briefly, as history, so that the student understands what cloth has cost and why safe, honest work matters.

FIBERS FROM PLANTS

Every thread you have ever worn began as something else. This unit starts with the fibers that grow in fields: cotton, the seed hair of a shrub; flax, whose stem gives linen; and the coarse, strong stems and leaves that give hemp, jute and ramie. All of them are built from one molecule, cellulose, a chain of thousands of glucose rings held together by hydrogen bonds. Once you understand cellulose you can predict how a plant fiber behaves: why cotton drinks water, why linen feels cool and wrinkles, why both get stronger when wet, and why both burn like paper.

The stories run from Eli Whitney's gin of 1793, and the hard history it set in motion, to John Mercer's caustic bath of 1844 and the retting ponds and scutching boards of the flax country. The labs make you a fiber scientist: you will gin cotton by hand and measure its staple, test cotton's strength wet and dry, compare mercerized and plain thread, measure how linen wrinkles and dries, and finish with a burn-and-feel identification lab that becomes your unit project, a labeled plant-fiber identification kit.

PREREQUISITES

- Comfortable with percents, ratios and a calculator (Algebra I)
- Can measure to the nearest millimeter and weigh to the nearest gram
- A parent available to stand beside you for the Lesson 1.5 burn test

MASTERY CHECKLIST

- ☐ I can describe the structure of a cotton fiber and explain how cellulose's hydrogen bonds make plant fibers absorbent, strong when wet and quick to wrinkle.
- ☐ I can tell the story of the cotton gin honestly, including how it made slavery in the South grow.
- ☐ I can calculate lint turnout, moisture regain, percent change in strength and fiber masses in a blend.
- ☐ I can explain what mercerization does to a cotton fiber and why mercerized thread is stronger and brighter.
- ☐ I can explain how flax becomes linen (pulling, retting, breaking, scutching, hackling) and why linen wrinkles and feels cool.
- ☐ I can identify cellulose fibers by burn and feel, safely, with a parent beside me.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **A 10× linen tester (thread counter):** A folding magnifier with a 1-inch or 1-centimeter window, sold at fabric and hobby stores for a few dollars. You will use it every unit this year.
- **Raw seed cotton or cotton bolls:** Craft stores sell dried cotton stems in the floral aisle, and homeschool science suppliers sell seed cotton by the bag. If none is available, Lesson 1.1's staple test works with plain cotton balls.
- **A kitchen scale reading 0.1 gram:** Inexpensive pocket scales read to 0.1 g. A 1-gram kitchen scale works if you weigh larger samples.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

1.1 King Cotton: The Boll, the Gin and the Honest History	3 sessions of 50 minutes
1.2 Cellulose Under the Lens	3 sessions of 50 minutes
1.3 John Mercer's Caustic Bath	3 sessions of 50 minutes
1.4 Flax and Fine Linen	3 sessions of 50 minutes
1.5 Hemp, Jute, Ramie and the Burn-and-Feel Lab	3 sessions of 50 minutes

1.1 KING COTTON: THE BOLL, THE GIN AND THE HONEST HISTORY

OBJECTIVES

- Describe how a cotton fiber grows from the seed and how cotton is picked, ginned and baled.
- Tell the story of Eli Whitney's gin honestly, including how it made cotton cheap and slavery in the South grow.
- Calculate lint turnout, bale counts and staple length in inches and millimeters.

Warm-up. Read the fiber-content tags on ten garments in your house and tally how many contain cotton. Then guess: of every ten pounds of fluffy cotton picked from a field, how many pounds are fiber and how many are seed? Write your guess down; you will test it this week.

WATCH

How Cotton Is Farmed | Georgia Cotton

GPB Education · 7:40

<https://www.youtube.com/watch?v=2tuSifDu8Mo>

WHEN TO WATCH

After “From field to bale.” Watch the bolls open, the spindle pickers at work and the modules built at the field's edge, and notice how long the growing season lasts.

BACKUP VIDEO

Eli Whitney's Invention

NBC News Learn · 2:23

<https://www.youtube.com/watch?v=LiuYxA7JDx4>

A short history of Whitney's gin, with period engravings and the cotton figures that show how fast the crop, and slavery, grew.

KEY TERMS

boll

The seed pod of the cotton plant. When ripe it splits open, and the white fiber, attached to the seeds, fluffs out.

gin

Short for engine: a machine that separates cotton fibers from their seeds.

lint turnout

The weight of lint ginned from a load of seed cotton, as a percent of that load's weight.

lint

The long cotton fibers removed from the seed by ginning: the part that is spun into yarn.

staple length

The typical length of a sample of fibers. For cotton it is measured in inches, often in thirty-seconds of an inch, or in millimeters.

bale

A tightly pressed, wrapped block of ginned cotton. A standard U.S. bale holds about 480 pounds of lint.

CORE IDEAS

The story. In the spring of 1793 Eli Whitney, a young Yale graduate from Massachusetts, was staying at Mulberry Grove, the Georgia plantation of Catherine Greene, widow of General Nathanael Greene of the War for Independence. Planters there could grow upland cotton easily, but its short fibers clung so tightly to its green, fuzzy seeds that one worker could clean only about a pound of lint a day by hand. Whitney built a machine that did it mechanically and received a patent on March 14, 1794. It worked so well, and was so simple to copy, that he spent years in court and made little money from it.

How they figured it out. Whitney's gin was a wooden box with a cylinder studded with wire teeth. As the cylinder turned, the teeth reached through narrow slots in a grate and dragged the fibers through; the slots were too narrow for the seeds, which fell away. A second cylinder of brushes, turning faster, swept the lint off the teeth. In 1796 Hodgen Holmes patented a gin with circular saws in

place of wire teeth, and the saw gin is still the basic design. A small hand gin could clean about 50 pounds of lint a day, fifty times the work of hand cleaning.

The honest history. The gin made short-staple cotton cheap to clean, and cotton spread across the Deep South to feed the mills of England and New England. Sadly, it also made slavery in the American South grow: planters bought more enslaved people to plant and pick the new fields, and the number of enslaved people in the United States rose from about 700,000 in the 1790 census to nearly 4 million by 1860. A machine meant to save labor ended up multiplying forced labor, and the nation paid for it in the Civil War. Inventions are never morally neutral in their use, and an honest student of cloth should know what cotton has cost.

The fabric science. Each cotton fiber is a single plant cell, a hair growing from the seed coat. For about three weeks after the flower opens, the cell grows longer; for several more weeks it lays down layer after layer of cellulose inside its wall. When the boll opens and the fiber dries, the hollow center (the *lumen*) collapses, and the fiber becomes a flat, twisted ribbon. Those natural twists, called convolutions, let fibers grip each other when they are spun. Length matters most: upland cotton, almost all of the U.S. crop, has a staple of roughly 1 to 1½ inches, while extra-long-staple Pima and Egyptian cottons run 1¾ inches and more. Longer fibers make smoother, stronger, finer yarn, because each fiber is caught by more twist.

From field to bale. Today spindle pickers twist the lint off the open bolls, and stripper harvesters pull off whole bolls. The seed cotton is packed into modules and trucked to a gin, where it is dried, cleaned, ginned on saw stands, cleaned again and pressed into bales of about 480 pounds. Only about a third of the seed cotton's weight comes out as lint; the rest is seed, which is crushed for oil and fed to cattle, plus trash. A sample from every bale is graded by the U.S. Department of Agriculture for staple length, strength, fineness, color and trash.

The studio lab. This week you will be the gin. You will weigh seed cotton, clean it by hand against a timer, weigh lint and seed to find your lint turnout, and measure the staple length of your lint the way a cotton classer does, by pulling and laying a tuft on black paper. Then you will compare your hand-ginning speed with Whitney's machine.

PICTURE STUDY



The Cotton Pickers, Winslow Homer, 1876 · Oil on canvas · Los Angeles County Museum of Art

Image: [Wikimedia Commons](#), public domain

Winslow Homer painted this in 1876, eleven years after the Civil War, from sketches made in Virginia. The two women are free, but they are still picking cotton by hand, as the South's workers had for generations. Homer gives them a quiet dignity and makes the field stretch out of sight behind them.

Look closely

- Find the open bolls. How high on the plant do they sit, and how would you pick one without catching your hand on the dry, sharp bracts?
- Look at the sack on the shoulder of the woman at the right. What does its size tell you about how much cotton a day's picking meant?
- Follow the field back to the horizon. How does Homer show how much work remains?

- Compare the two faces. What does each one seem to be thinking?

Talk about it

1. Picking, not ginning, stayed hand work until the 1940s. How does this painting help explain why the gin increased the demand for workers?
2. Homer could have painted a cheerful harvest scene. Why do you think he chose to show tired, serious women?
3. Every lint fiber in that sack is still attached to a seed. What has to happen next before it can become thread?

Safety first. This lab uses a scale, scissors and dry cotton. Dry cotton stems and bracts have sharp points, so handle bolls with care. Start the year's habit now: pins and needles live in a pincushion or magnetic dish, counted out and counted back in every session, away from babies, toddlers and pets.

STUDIO LAB

Be the Gin: Lint Turnout and Staple Length

Question: What fraction of seed cotton is fiber, and how long are the fibers? You will gin a sample by hand, find your lint turnout, measure staple length the way a classer does, and compare your speed with Whitney's gin. If you cannot get seed cotton, do the staple test with cotton balls and use the turnout data given in the tips.

You will need

- 20–30 g of seed cotton or 3–5 dried cotton bolls (or a bag of 100% cotton balls)
- A scale reading 0.1 g, a timer and a ruler marked in millimeters
- A sheet of black construction paper or black felt
- A 10× magnifier and tweezers
- Two small labeled bowls or zip-top bags (lint, seed)

Steps

1. **Hypothesis.** Write your warm-up guess as a hypothesis: “Lint will be about ___% of the seed cotton's weight.”
2. Weigh the seed cotton to 0.1 g and record it. Note the variety if the label gives it.
3. Start the timer and gin by hand: pull the lint off each seed with your fingers, lint into one bowl, seeds into the other. Stop the timer when done.
4. Weigh the lint and the seeds. Add them; the difference from the starting mass is trash (leaf and stem bits) plus loss. Record all four numbers in a data table.
5. **Staple test.** Take a pinch of lint. Grip it at one end and pull the other side away; discard the loose fibers; layer and pull again three or four times until the fibers lie parallel. Lay the tuft on black paper and measure the length of the bulk of the fibers to the nearest millimeter. Repeat for 10 tufts.
6. Repeat the staple test with a pulled cotton ball, and with fibers teased from a cotton T-shirt scrap if you like. Record in the same table.
7. Look at single fibers under the magnifier. Sketch the flat, twisted ribbon and count twists in one visible length if you can.
8. **Calculate** your turnout, your mean staple and range for each sample, and your ginning rate in pounds per 10-hour day. Compare with 1 pound by hand and 50 pounds for a small gin.
9. **Conclude.** Was your hypothesis close? Which sample had the longest staple, and what kind of cotton do you think it was?
10. **Repeat round.** Gin a second, equal sample now that you have the knack. Did your rate improve, and did your turnout change?

Tips

- No seed cotton? Use typical values for the turnout calculation: 1,500 lb of seed cotton giving 525 lb of lint and about 825 lb of seed.
- Classers call staple in thirty-seconds of an inch. Convert your millimeters back (divide by 25.4, multiply by 32) and see what a classer would call your sample.

- Cotton balls are made of shorter, bleached fibers and sometimes comber noils (short fibers combed out of fine yarn), so expect a shorter staple than fresh lint.

Check your work

- ☐ I recorded every mass to 0.1 g in a data table and calculated turnout with the formula.
- ☐ I measured 10 staple tufts and reported a mean and a range in mm and in thirty-seconds of an inch.
- ☐ I compared my rate with Whitney's gin and wrote a conclusion the data support.

LAB NOTEBOOK

1. Draw a cotton boll split open, with one seed and its fibers, and label boll, bract, seed, lint and fuzz (the short fibers left on the seed).
2. Tape a tuft of your measured lint to the page under clear tape and write its staple in mm and thirty-seconds.
3. Write a five-sentence summary of the gin's history that a younger sibling could understand, without leaving out slavery.

KEY FORMULAS

$$\text{lint turnout} = \frac{\text{mass of lint}}{\text{mass of seed cotton}} \times 100\%$$

$$\text{lint turnout} = \text{mass of seed cotton} \div \text{mass of lint} \times 100\%$$

$$\text{inches} = \frac{\text{thirty-seconds}}{32}, \quad \text{mm} = \text{inches} \times 25.4$$

$$\text{inches} = 32 \div \text{thirty-seconds}, \quad \text{mm} = \text{inches} \times 25.4$$

From history. Whitney never got rich from the gin, but he went on to promote interchangeable parts under a 1798 federal contract for firearms. His Connecticut armory is remembered as an early step toward the American system of manufacturing, the same system that would later make sewing machines cheap enough for ordinary homes.

WORKED EXAMPLES

Example 1. A load of 1,500 lb of seed cotton yields 525 lb of lint. Find the lint turnout. How many 480-lb bales would 12,000 lb of seed cotton make at that turnout?

Show solution

$$1. \text{ Turnout: } \frac{525 \text{ lb}}{1,500 \text{ lb}} \times 100\% = 35\% \quad 1,500 \text{ lb} \div 525 \text{ lb} \times 100\% = 35\%.$$

$$2. \text{ Lint from 12,000 lb: } 12,000 \text{ lb} \times 0.35 = 4,200 \text{ lb} \quad 12,000 \text{ lb} \times 0.35 = 4,200 \text{ lb}.$$

$$3. \text{ Bales: } 4,200 \text{ lb} \div 480 \text{ lb/bale} = 8.75 \text{ bales} \quad 4,200 \text{ lb} \div 480 \text{ lb/bale} = 8.75 \text{ bales}.$$

Answer: Turnout 35%; 8 full bales with three-quarters of a ninth.

Example 2. A classer calls an upland sample “36” (thirty-seconds of an inch) and a Pima sample “48.” Convert both to inches and millimeters.

Show solution

$$1. \text{ Upland: } \frac{36}{32} \text{ in} = 1.125 \text{ in} \quad 36 \text{ in} = 1.125 \text{ in}; 1.125 \times 25.4 = 28.6 \text{ mm} \quad 1.125 \times 25.4 = 28.6 \text{ mm}.$$

$$2. \text{ Pima: } \frac{48}{32} \text{ in} = 1.5 \text{ in} \quad 48 \text{ in} = 1.5 \text{ in}; 1.5 \times 25.4 = 38.1 \text{ mm} \quad 1.5 \times 25.4 = 38.1 \text{ mm}.$$

Answer: Upland $1\frac{1}{8}$ in (28.6 mm); Pima $1\frac{1}{2}$ in (38.1 mm), one-third longer.

Example 3. Hand cleaning yields about 1 lb of lint per worker per day; a small hand gin yields about 50 lb a day. How many hand workers equal one gin over a 6-day week, and how many days would one hand worker need to clean one 480-lb bale?

Show solution

1. Per week, the gin cleans $50 \times 6 = 300$ lb; one hand worker cleans $1 \times 6 = 6$ lb.
2. Workers matched: $300 \div 6 = 50$ workers.
3. One bale by hand: $480 \text{ lb} \div 1 \text{ lb/day} = 480$ days.

Answer: One gin did the work of 50 hand cleaners; a bale took one person about 480 working days by hand.

PRACTICE

1. **Easy** What part of the cotton plant is the fiber, and what is the boll?

Show answer

The fiber is a seed hair, a single cell growing from the seed coat; the boll is the seed pod that splits open when ripe.

2. **Easy** Convert a staple of $34/32$ inch to inches and millimeters.

Show answer

$$34/32 = 1.0625 \text{ in} \approx 27.0 \text{ mm}$$

3. **Easy** In what year did Whitney receive his gin patent, and who patented the saw gin two years later?

Show answer

1794; Hodgen Holmes, in 1796.

4. **Medium** A gin turns 2,000 lb of seed cotton into 760 lb of lint. Find the turnout.

Show answer

$$760/2,000 \times 100\% = 38\%$$

5. **Medium** At 36% turnout, how much seed cotton is needed for one 480-lb bale?

Show answer

$$480 \div 0.36 \approx 1,333 \text{ lb}$$

6. **Medium** A field produces 1,100 lb of lint per acre. How many 480-lb bales is that per acre, and how many bales from 250 acres?

Show answer

$$1,100/480 \approx 2.29 \text{ bales per acre; } 2.29 \times 250 \approx 573 \text{ bales.}$$

7. **Medium** Why do longer fibers make stronger, smoother yarn?

Show answer

Each long fiber is wrapped by more turns of twist and touches more neighbors, so friction holds it better, and fewer fiber ends stick out of the yarn surface.

8. **Hard** In your lab you cleaned 18.0 g of seed cotton in 25 minutes and got 6.3 g of lint. Find your turnout and your rate in pounds of lint per 10-hour day (1 lb = 453.6 g).

Show answer

$$\text{Turnout } 6.3/18.0 = 35\%; \text{ rate } 6.3 \text{ g} \times 24 = 151 \text{ g per 10 h, } 151/453.6 \approx 0.33 \text{ lb per day.}$$

9. **Hard** The census counted about 700,000 enslaved people in 1790 and about 3.95 million in 1860. By what percent did the number grow?

Show answer

$$(3.95 - 0.70)/0.70 \times 100\% \approx 464\%$$

10. **Hard** Seed is about 55% of seed cotton's weight. From a 480-lb bale at 35% turnout, about how much seed was separated?

Show answer

Seed cotton $480/0.35 \approx 1,371$ lb $480/0.35 \approx 1,371$ lb; seed $0.55 \times 1,371 \approx 754$ lb $0.55 \times 1,371 \approx 754$ lb.

11. **Challenge** From the lesson's story: Whitney meant his gin to save labor, yet it multiplied forced labor. Explain the economics in three sentences, and name one lesson for inventors today.

Show answer

Cleaning was the bottleneck; once the gin removed it, short-staple cotton became cheap and profitable to grow on vast new lands. Planting and picking were still done by hand, so planters bought more enslaved people to work more fields. A tool's effects depend on the system it enters; inventors should ask who will bear the cost of their success.

COMMON MISTAKES

- Confusing seed cotton with lint. Seed cotton is what comes off the plant; lint is what is left after ginning.
- Measuring one long fiber and calling it the staple. Staple is the typical length of the bulk of a tuft, not the longest hair.
- Telling the gin's story as pure progress, or as pure evil. Tell it whole: a clever machine, a cheaper cloth, and a terrible growth in slavery.

Make it a game · Tag Tally Race. Each player gets two minutes and one closet or drawer. Read tags and tally every garment by its main fiber: cotton, other plant, animal, made by people. Score one point per tagged garment and three bonus points for anyone who finds a fiber nobody else found. Then everyone guesses the household's cotton percentage before the totals are added; closest guess wins a bonus.

1.2 CELLULOSE UNDER THE LENS

OBJECTIVES

- Describe cellulose as a long chain of glucose units and explain how hydrogen bonds and crystalline and amorphous regions give plant fibers their properties.
- Explain why cotton absorbs water, wrinkles, and is stronger wet than dry.
- Calculate moisture regain, moisture content and percent change in strength.

Warm-up. Drip one drop of water onto a cotton dish towel and one onto a polyester shirt or fleece. Time how long each drop takes to disappear. Write one sentence guessing why they differ.

WATCH

A-Level Biology - Carbohydrates: Polysaccharides - Starch | Glycogen | Cellulose (2027/28 exams)

Cognito · 6:46

<https://www.youtube.com/watch?v=S4T4KVTSGdA>

WHEN TO WATCH

After “The fabric science.” Pause on the drawings of the cellulose chain and find where neighboring chains hydrogen-bond; compare cellulose with starch.

KEY TERMS

cellulose

A natural polymer made of thousands of glucose units joined end to end; the main substance of plant cell walls and of cotton, linen, hemp and rayon.

hydrogen bond

A weak attraction between a hydrogen atom on one –OH group and an oxygen atom nearby. Millions of them together hold cellulose chains tightly side by side.

amorphous region

A part of a fiber where chains are loosely and irregularly arranged. Water and dyes enter here.

polymer

A very long molecule built from many repeating small units (monomers).

crystalline region

A part of a fiber where polymer chains are packed in a regular, tightly bonded order. Strong and stiff; water cannot easily enter.

moisture regain

The mass of water a fiber holds at standard conditions (21 °C, 65% relative humidity), as a percent of its bone-dry mass. Cotton's is about 8.5%.

CORE IDEAS

The story. In 1838 the French chemist Anselme Payen treated wood and other plant tissues with acids and ammonia and found that, whatever plant he began with, the same tough white fibrous substance remained. It had the same composition as starch but behaved completely differently. He named it *cellulose*, the stuff of cells. Payen had found the most abundant natural polymer on earth, the material of every leaf, stem and tree trunk, and of every cotton shirt and linen towel.

How they figured it out. Payen could weigh and analyze cellulose, but its shape was a mystery for nearly a century. In the 1920s chemists, led by Hermann Staudinger in Germany, argued that such substances were giant chain molecules, not clumps of small ones, and X-ray studies of cotton and ramie fibers showed regular, crystal-like order inside them. Cellulose turned out to be a chain of glucose rings, each flipped relative to its neighbor, joined into a straight, flat ribbon thousands of units long; in cotton, often around 10,000.

The fabric science. Each glucose unit in the chain carries three hydroxyl groups (–OH). Because the chain is straight and flat, neighboring chains line up and hydrogen-bond to each other by the million, forming tightly packed *crystalline* regions, roughly two-thirds of a cotton fiber, which give strength. Between them lie looser *amorphous* regions. Water molecules are attracted to the –OH groups and slip into the amorphous regions, which is why cotton drinks water and holds about 8.5% of its dry weight as moisture

even in ordinary air. That same water lets chains slide and re-bond in new positions when the fiber is bent, which is why cotton wrinkles, and why heat and moisture from an iron let you press the wrinkles out.

Wet strength. Most fibers are weaker wet. Cotton and linen are the exception: cotton is roughly 10 to 20 percent stronger wet. The usual explanation is that water swells the fiber, relieving stress at weak points and letting the spiraling fibrils share the load more evenly. This is why a cotton towel can be wrung hard and why cotton survives hot, vigorous laundering that would ruin many other fibers. Rayon, made of the same cellulose but with shorter chains and less crystalline order, goes the other way and loses much of its strength when wet, as you will see in Unit 3.

Look closely. Under a 10× lens a single cotton fiber is a flattened, twisted ribbon, about 12 to 20 micrometers wide, finer than a human hair. A good microscope shows its layers: a thin waxy cuticle, the primary wall, a thick secondary wall of nearly pure cellulose in spiral fibrils, and the collapsed lumen in the middle. The wax is why raw cotton repels water at first; mills scour it away so cotton becomes the absorbent fiber we know.

The studio lab. You will test the claim that cotton is stronger wet than dry by loading identical cotton threads until they break, dry and wet, and you will compare how fast cotton, linen and polyester absorb a drop of water. Same thread, same length, same loading method: only the water changes.

PICTURE STUDY



Cotton Merchants in New Orleans, Edgar Degas, 1873 · Oil on canvas · Harvard Art Museums (Fogg Museum), Cambridge, Massachusetts
Image: [Wikimedia Commons](#), public domain

Degas visited his mother's family in New Orleans in 1872–73, where his uncle and brothers were in the cotton trade, and he painted the cotton office more than once. In this version, buyers handle and examine heaps of ginned cotton. The price of a whole crop depended on what such men saw and felt in their fingers.

Look closely

- Find the man in the straw hat holding up a tuft of cotton. What is he checking for, and how is it like the staple test you will do?
- Look at the man in the top hat with his hands in the cotton. What might he learn by feel that he could not see?
- Notice the light. Why would a cotton buyer want good daylight to judge cotton's color?
- Look at how loosely Degas painted the cotton itself. How does he make it look soft and fluffy?

Talk about it

1. The whole price of a crop hung on staple length, color and cleanliness. Which of those could these men judge by eye and hand, and which needed a ruler?
2. Today USDA classing offices measure cotton with machines. What would a machine measure better than a buyer's fingers, and what might the fingers still notice?
3. Degas painted this eight years after the Civil War. Whose work is missing from this tidy office?

Safety first. Hang test weights over a soft surface and keep feet clear of the bucket in case a thread breaks suddenly. Wipe up spilled water at once so no one slips. Keep needles and pins in the pincushion and count them at the end of the session.

STUDIO LAB

Wet versus Dry: Is Cotton Really Stronger Wet?

Question: Does soaking cotton thread in water change the load it can hold before breaking? You will hang a container from identical lengths of cotton thread, add water until each breaks, and compare dry and wet breaking loads. Then you will run a quick absorbency test on three fabrics.

You will need

- A spool of 100% cotton thread or size 10 cotton crochet thread (not polyester, not cotton-wrapped polyester)
- A small plastic bucket or 1-quart yogurt tub with a wire handle, and a measuring cup
- A broom handle or dowel laid across two chair backs
- A kitchen scale, a timer, scissors and masking tape
- Swatches of cotton, linen and polyester, an eyedropper and a glass of water

Steps

1. **Hypothesis.** Write your prediction: will wet cotton thread hold more, less or the same load as dry, and by about how much?
2. Cut 10 pieces of thread, each 30 cm long, from the same spool. Label five “dry” and five “wet.” Soak the wet five in water for 10 minutes.
3. Tie one dry thread in a loop around the dowel and through the bucket handle with the same knot each time (a square knot), so the free length is the same for every test.
4. Pour water into the bucket slowly, about 50 mL at a time, waiting a few seconds between pours, until the thread breaks. Weigh the bucket and water together; that mass is the breaking load. Record it.
5. Repeat for all five dry threads, then for the five wet ones, testing each wet thread straight from the water.
6. Note where each thread broke. A break at the knot means the knot, not the thread, was the weak point; mark those results.
7. Calculate the mean breaking load for dry and wet, the range of each, and the percent change.
8. **Absorbency test.** Lay the three swatches flat. Drop one drop of water on each from the same height and time how long until the shine disappears (stop at 60 seconds). Repeat three times and average.
9. **Conclude.** Did the data support your hypothesis? Is the difference bigger than the scatter within each group?
10. **Repeat round.** If more than two threads broke at the knot, change the knot (a bowline or a wrap around the dowel) and run the test again.

Tips

- Slow, even pouring matters: a sudden splash is a jolt, not a steady load.
- If the threads hold more than your bucket can carry, double the cut length to a single strand, or use finer sewing thread.
- A sizing or finish on new thread can affect results. Note the brand and whether the thread was mercerized; Lesson 1.3 explains why that matters.

Check your work

- ☐ I changed only one variable (wet or dry) and kept thread, length, knot and pouring method the same.
- ☐ I reported means, ranges and percent change with units.
- ☐ I wrote a conclusion that compares the difference with the scatter in my data.

LAB NOTEBOOK

1. Draw a short section of a cellulose chain as a row of hexagons, mark the –OH groups, and draw a second chain beside it with dotted lines for hydrogen bonds.
2. Sketch a cotton fiber as you saw it under the magnifier, and label convolution, lumen and the direction of twist.

3. Make your data table for the strength test, then a bar graph of mean dry and wet breaking loads with the range shown as a line on each bar.

KEY FORMULAS

$$\text{moisture regain} = \frac{m_{\text{conditioned}} - m_{\text{dry}}}{m_{\text{dry}}} \times 100\%$$

$$\text{moisture regain} = m_{\text{dry}} m_{\text{conditioned}} - m_{\text{dry}} \times 100\%$$

$$\text{moisture content} = \frac{m_{\text{conditioned}} - m_{\text{dry}}}{m_{\text{conditioned}}} \times 100\%$$

$$\text{moisture content} = m_{\text{conditioned}} m_{\text{conditioned}} - m_{\text{dry}} \times 100\%$$

$$\text{percent change} = \frac{\text{new} - \text{original}}{\text{original}} \times 100\%$$

$$\text{percent change} = \text{original} \text{new} - \text{original} \times 100\%$$

WORKED EXAMPLES

Example 1. A cotton swatch weighs 20.0 g after drying in a low oven and 21.7 g after a day in a room at standard conditions. Find its moisture regain and its moisture content.

Show solution

1. Water held: $21.7 \text{ g} - 20.0 \text{ g} = 1.7 \text{ g}$
2. Regain (on dry mass): $\frac{1.7 \text{ g}}{20.0 \text{ g}} \times 100\% = 8.5\%$
3. Content (on total mass): $\frac{1.7 \text{ g}}{21.7 \text{ g}} \times 100\% = 7.8\%$

Answer: Regain 8.5%, moisture content 7.8%. Regain is the trade's standard because it is based on the unchanging dry mass.

Example 2. Five dry cotton threads broke at loads of 1,480, 1,520, 1,450, 1,560 and 1,490 g. Five wet threads broke at 1,700, 1,760, 1,690, 1,780 and 1,720 g. Find each mean and the percent change from dry to wet.

Show solution

1. Dry mean: $\frac{7,500 \text{ g}}{5} = 1,500 \text{ g}$
2. Wet mean: $\frac{8,650 \text{ g}}{5} = 1,730 \text{ g}$
3. Change: $\frac{1,730 - 1,500}{1,500} \times 100\% = 15.3\%$

Answer: Wet cotton was about 15% stronger, within the 10–20% range expected. The ranges (110 g and 90 g) are smaller than the 230 g difference, so the effect is real.

Example 3. A mill buys 10,000 kg of cotton weighed at 10.5% regain, but the contract price assumes the standard 8.5%. What is the correct invoice weight?

Show solution

1. Dry mass: $\frac{10,000 \text{ kg}}{1.105} = 9,050 \text{ kg}$
2. Invoice weight at standard regain: $9,050 \text{ kg} \times 1.085 = 9,819 \text{ kg}$

Answer: About 9,819 kg; the buyer should not pay for 181 kg of extra water.

PRACTICE

1. **Easy** What small molecule is the repeating unit of cellulose?

Show answer

Glucose.

2. **Easy** Which regions of a fiber do water and dyes enter: crystalline or amorphous?

Show answer

Amorphous.

3. **Easy** Who named cellulose, and in what year did he isolate it?

Show answer

Anselme Payen, 1838.

4. **Medium** A swatch weighs 12.0 g dry and 13.0 g conditioned. Find its regain.

Show answer

$$1.0/12.0 \times 100\% = 8.3\% \quad 1.0/12.0 \times 100\% = 8.3\%$$

5. **Medium** A cotton towel has a dry mass of 400 g. How much water does it hold at 8.5% regain?

Show answer

$$400 \times 0.085 = 34 \text{ g} \quad 400 \times 0.085 = 34 \text{ g}$$

6. **Medium** Explain in two sentences why cotton wrinkles and why a steam iron removes the wrinkles.

Show answer

Bending lets water-loosened hydrogen bonds break and re-form with chains in new, bent positions. Heat and moisture loosen them again, and pressing flat lets them re-form in the flat position as the cloth cools and dries.

7. **Medium** A dry thread breaks at 900 g and the same thread wet at 1,035 g. Find the percent change.

Show answer

$$135/900 \times 100\% = 15\% \quad 135/900 \times 100\% = 15\% \text{ stronger wet.}$$

8. **Hard** A sample has 9.0% moisture content. What is its regain?

Show answer

$$\text{In 100 g there are 9 g water and 91 g dry fiber: } 9/91 \times 100\% = 9.9\% \quad 9/91 \times 100\% = 9.9\%.$$

9. **Hard** Raw (unscoured) cotton floats on water for a while; scoured cotton sinks quickly. Explain.

Show answer

Raw cotton's waxy cuticle repels water, so air stays trapped. Scouring removes the wax, exposing the -OH groups, so water wicks in at once.

10. **Hard** A shipment of 5,000 kg was weighed at 7.0% regain. Find its invoice weight at the standard 8.5%.

Show answer

$$5,000/1.070 \times 1.085 \approx 5,070 \text{ kg} \quad 5,000/1.070 \times 1.085 \approx 5,070 \text{ kg}$$

11. **Challenge** Starch and cellulose are both made of glucose, yet bread dissolves in your mouth while a cotton shirt survives years of hot washing. Explain the difference using chain shape and hydrogen bonding.

Show answer

Cellulose's glucose units alternate orientation, making straight, flat chains that pack tightly and hydrogen-bond into strong crystals water cannot pull apart. Starch's linkages make coiled, branched chains that cannot pack, so water and enzymes get in easily.

COMMON MISTAKES

- Saying cotton is “made of sugar.” It is made of glucose units joined into a polymer that behaves nothing like sugar.
- Mixing up regain and moisture content. Regain divides by the dry mass; content divides by the conditioned mass.

- Testing wet threads after they have half-dried on the table. Test straight from the water, or the comparison is not fair.

Make it a game · Drop Duel. Gather eight fabrics from the rag bag. Each player secretly ranks them from fastest to slowest at absorbing a water drop. Then drop water on each and time it. Score one point for every fabric placed within one position of its true rank. The winner explains the top and bottom fabric using the words cellulose and hydrogen bond.

Scripture. “Consider the lilies of the field, how they grow; they toil not, neither do they spin.” (Matthew 6:28, KJV)

The lilies are clothed in cellulose they did not spin. Every cotton boll and flax stem is God's design before it is anyone's craft, and studying it closely is a way of considering how they grow.

1.3 JOHN MERCER'S CAUSTIC BATH

OBJECTIVES

- Tell how John Mercer discovered mercerization in 1844 and how Horace Lowe's use of tension made it a commercial finish.
- Explain what sodium hydroxide does to a cotton fiber and why mercerized cotton is stronger, brighter and takes dye more deeply.
- Compare mercerized and plain cotton thread by strength, luster and dye uptake, and calculate percent differences.

Warm-up. Find a spool of cotton sewing thread or a skein of “perle” embroidery cotton, and a plain cotton string or kitchen twine. Hold them side by side in window light. Describe the difference in shine and feel in two sentences.

WATCH

What is mercerized yarn and how does it compare to unmercerized yarn?

Yarn Barn of Kansas · 9:34

<https://www.youtube.com/watch?v=Wa5jSdrGu00>

WHEN TO WATCH

After “The fabric science.” Watch the side-by-side comparison of mercerized and unmercerized yarn and note every difference the presenter names.

BACKUP VIDEO

Mercerization process | mercerizing process in textile | mercerization process of cotton fabric

TEXTYLES · 2:49

<https://www.youtube.com/watch?v=8LZefBE-JPw>

A short animation of a mill mercerizing range. Notice where the fabric is held under tension.

KEY TERMS

mercerization

Treating cotton with a strong solution of sodium hydroxide, usually under tension, then washing and neutralizing it, which swells the fibers and makes them rounder, stronger, more lustrous and more absorbent of dye.

luster

The way a fiber or fabric reflects light. Smooth, round fibers reflect more evenly and look brighter.

perle cotton

A mercerized, tightly twisted, non-divisible cotton thread used for embroidery, prized for its sheen.

sodium hydroxide

NaOH, also called caustic soda or lye: a strong base that swells cellulose. It burns skin and eyes and is used only in industry for this purpose.

dye uptake

How much dye a fiber absorbs from a dye bath under the same conditions; deeper color means more uptake.

CORE IDEAS

The story. John Mercer (1791–1866) began work as a boy in the cotton mills and calico-printing works of Lancashire, England, and taught himself chemistry from books. In 1844, while filtering a strong solution of caustic soda through cotton cloth, he noticed that the cloth had changed: it had shrunk, thickened, become stronger, and now took dye more deeply than ordinary cotton. He patented the treatment in 1850. But the shrinkage made the cloth smaller and the process costly, and for forty years mills mostly ignored it.

How they figured it out. The missing piece came in 1889–1890, when another English chemist, Horace Lowe, tried treating cotton while it was stretched tight so it could not shrink. The yarn came out with a high, silky luster. Within a few years mercerizing under tension was a standard finish for fine cotton thread, yarn and fabric, and it still is. A common sewing thread from the early 1900s on was labeled “mercerized” on the spool, and many good cotton threads still are.

The fabric science. Strong sodium hydroxide, around 20 percent, pushes in among the cellulose chains and swells each fiber dramatically. The flattened, bean-shaped cross-section becomes round, the collapsed lumen nearly closes, and the natural convolutions untwist. Inside, the chains rearrange into a slightly different crystal form, with more of the fiber opened to water. After the caustic is washed out and neutralized with a weak acid, the changes stay. A round, smooth fiber reflects light evenly: luster. Fibrils pulled into line under tension share load better: strength, often 15 to 20 percent more. More accessible amorphous region: deeper, faster dyeing, with less dye needed for the same shade.

Why you will not mercerize at home. Sodium hydroxide at mercerizing strength causes severe chemical burns to skin and blindness if it splashes into eyes, and it releases heat when dissolved. Mills handle it in enclosed machinery with protective equipment and recover the caustic for reuse. In this course we study mercerization by comparing finished threads, not by making them. Your lab uses only water, tea and a scale.

The studio lab. You will compare mercerized cotton thread with unmercerized cotton string of similar size: luster under a lamp, breaking load with the bucket method from Lesson 1.2, and dye uptake in a jar of strong tea, whose tannins dye cellulose a tan-brown. The question is whether a finish you cannot see under a 10× lens still shows up in measurements.

PICTURE STUDY



Sea Island Cotton (Gossypium barbadense), From Köhler's Medizinal-Pflanzen, edited by Franz Eugen Köhler, 1887 · Chromolithograph botanical plate · Published in Gera, Germany; copies in many botanical libraries
Image: [Wikimedia Commons](#), public domain

Gossypium barbadense is the species of the long-staple cottons: Sea Island, Egyptian and Pima. Its long, fine fibers are the ones mercerized for the finest thread and shirting. Nineteenth-century botanical plates like this were drawn to teach doctors and students to identify plants exactly, part by part.

Look closely

- Find the small drawing of a seed with its white fibers spread out around it (upper right). How long are the fibers compared with the seed?
- Find the drawings of a boll cut across. How many sections does it have, and where do the seeds sit?
- Look at the flower. Cotton flowers last about a day; count the days from flower to open boll if a boll takes about seven or eight weeks.
- Compare the size of the leaf with the boll. Where on the plant would a picker reach?

Talk about it

1. This plate shows the species that makes long-staple cotton. Why would long fibers matter even more for thread that will be mercerized and sold for its luster?
2. A botanical artist must be exact. What details of cotton would you include if you were drawing one plate to teach a mill chemist?

3. Mercer worked with cloth, not plants. What could a mill chemist learn by studying the plant itself?

Safety first. Do not attempt to mercerize anything at home: caustic soda at mercerizing strength burns skin and eyes. The tea bath in this lab uses hot tap water in a glass jar set aside for lab work, never a pot or utensil used for food; let it cool before handling the threads, and wipe spills promptly.

STUDIO LAB

Mercerized or Not? A Three-Test Comparison

Question: Does mercerization make a measurable difference in luster, strength and dye uptake? You will compare a mercerized cotton thread with an unmercerized cotton thread or string of similar thickness.

You will need

- Mercerized cotton thread or perle cotton (the label says “mercerized”)
- Unmercerized cotton string, crochet cotton or twine of similar thickness (check the label)
- The bucket-and-dowel load rig from Lesson 1.2, a scale and a measuring cup
- 4 black tea bags, a 1-quart glass jar set aside for lab work, hot tap water and a timer
- A desk lamp, a sheet of black paper and a white card

Steps

1. **Hypothesis.** For each test (luster, strength, dye), predict which thread wins and by how much.
2. **Luster.** Lay 10 cm of each thread side by side on black paper under the lamp. Photograph them from the same spot. Rate luster 1–5 and ask two family members to rate them without being told which is which.
3. **Strength.** Cut five 30 cm lengths of each. Break each with the bucket method, recording the breaking load. If the threads are different sizes, also weigh 1 m of each so you can compare strength per gram.
4. **Dye uptake.** Make a strong tea bath: 4 tea bags in 3 cups of hot tap water in the glass jar. Remove the bags after 10 minutes. Tie a 50 cm skein of each thread with a different knot pattern so you can tell them apart, wet them, and drop both into the jar together for 30 minutes.
5. Rinse both skeins in cool water until it runs nearly clear, and dry them flat. Compare their depth of color on the white card and photograph them together.
6. Calculate the mean breaking load, the strength per gram if needed, and the percent difference of mercerized from plain.
7. **Conclude.** Which differences were large and which might be explained by thread size or twist? What would you need to make the test perfectly fair?
8. **Repeat round.** Wash both dyed skeins five times in warm soapy water, dry them, and compare again. Which kept its color better?

Tips

- If you cannot find unmercerized thread of the same size, compare strength per gram (breaking load divided by grams per meter). That is how textile labs compare yarns of different sizes, as Unit 4 explains.
- Blind ratings are better science than your own: you know which thread is which and may see what you expect.
- Many cotton sewing threads today are mercerized; most kitchen twine and cotton string are not.

Check your work

- ☐ I ran all three tests with only the thread type changed and recorded measurements with units.
- ☐ I used blind ratings for luster.
- ☐ My conclusion names at least one possible flaw in the comparison and how to fix it.

LAB NOTEBOOK

1. Draw the cross-section of a cotton fiber before and after mercerizing: a flattened bean with a collapsed lumen, then a near circle. Label each.

2. Tape in 5 cm of each tea-dyed thread side by side, with your luster ratings and breaking loads beside them.
3. Write a short warning label for sodium hydroxide as a mill would post it: what it does, what protects workers, and what to do if it splashes.

KEY FORMULAS

$$\text{percent difference from control} = \frac{\text{treated} - \text{control}}{\text{control}} \times 100\%$$

$$\text{percent difference from control} = \text{control} \times \text{treated} - \text{control} \times 100\%$$

$$\text{concentration (w/w)} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$$

$$\text{concentration (w/w)} = \text{mass of solution} \times \text{mass of solute} \times 100\%$$

From history. Mercer was elected a Fellow of the Royal Society in 1852, a rare honor for a man who left school to work in a mill. Besides mercerizing, he worked on dyes and on chemical processes for calico printing, and he was remembered in Lancashire as a teacher who gladly shared what he knew with young workers.

WORKED EXAMPLES

Example 1. Unmercerized cotton yarn breaks at a mean load of 410 g; the same yarn mercerized breaks at 480 g. Find the percent increase.

Show solution

1. Difference: $480 \text{ g} - 410 \text{ g} = 70 \text{ g}$
2. Percent: $\frac{70 \text{ g}}{410 \text{ g}} \times 100\% = 17\%$

Answer: About 17% stronger.

Example 2. A mill's mercerizing bath of 1,200 kg contains 264 kg of sodium hydroxide dissolved in water. What is its concentration by mass? How much NaOH must be added to 1,000 kg of the bath to raise it to 24%, if the added NaOH is solid?

Show solution

1. Concentration: $\frac{264 \text{ kg}}{1,200 \text{ kg}} \times 100\% = 22\%$
2. In 1,000 kg of bath: 220 kg NaOH. Adding x kg: $\frac{220 + x}{1,000 + x} = 0.24$
3. Solve: $220 + x = 240 + 0.24x \Rightarrow 0.76x = 20 \Rightarrow x = 26.3 \text{ kg}$

Answer: 22%; add about 26 kg of NaOH. Notice you must add a little more than 20 kg, because the added solid also enlarges the total.

Example 3. Mercer's untensioned cloth shrank from 40 in to 30 in wide. Find the width shrinkage, and the width of cloth a printer needed to buy to finish at 36 in.

Show solution

1. Shrinkage: $\frac{40 - 30}{40} \times 100\% = 25\%$
2. Finished width is 75% of the starting width: $36 \text{ in} \div 0.75 = 48 \text{ in}$

Answer: 25% shrinkage; 48 in of grey cloth per 36 in finished, a costly loss, which is why tension (Lowe's idea) made the process practical.

PRACTICE

1. **Easy** What chemical did Mercer use, and in what year did he notice its effect?

Show answer

Sodium hydroxide (caustic soda), 1844.

2. **Easy** What did Horace Lowe add to the process, and what did it give?

Show answer

Holding the cotton under tension; it prevented shrinkage and produced a silky luster.

3. **Easy** Name three properties that improve when cotton is mercerized.

Show answer

Luster, strength and dye uptake (also absorbency).

4. **Medium** Why does a round fiber look brighter than a flat, twisted one?

Show answer

A smooth round surface reflects light evenly in a consistent direction; a twisted ribbon scatters light every which way, so it looks duller.

5. **Medium** Plain thread breaks at 620 g, mercerized at 735 g. Find the percent increase.

Show answer

$$115/620 \times 100\% \approx 18.5\%$$

6. **Medium** A 500 g solution contains 100 g NaOH. Find its concentration.

Show answer

$$100/500 \times 100\% = 20\%$$

7. **Medium** Why are mercerized fabrics dyed with less dye for the same shade?

Show answer

Swelling opens more amorphous, accessible cellulose, so more dye is absorbed and fixed per gram of fiber.

8. **Hard** Cloth shrinks 22% in width during untensioned mercerizing. What starting width gives 45 in finished?

Show answer

$$45 \div 0.78 \approx 57.7 \text{ in}$$

9. **Hard** How much water must be added to 400 kg of 25% NaOH solution to dilute it to 20%?

Show answer

NaOH is 100 kg; new total $100/0.20 = 500$ kg; add 100 kg of water.

10. **Hard** Explain why mercerization is done on cotton and linen but would be pointless on polyester.

Show answer

It works by swelling cellulose with hydroxide among -OH-rich chains. Polyester has no such hydroxyl-rich, swellable cellulose; strong base instead attacks and thins polyester's surface.

11. **Challenge** Design a fair test to show whether mercerized thread is more colorfast than plain thread after tea dyeing. Name the variable you change, three you control, and what you measure.

Show answer

Change: mercerized or not. Control: tea strength, time and temperature in the bath, rinse, thread size, wash method. Measure: shade before and after five washes against a gray or tan shade card, and color left in the wash water.

COMMON MISTAKES

- Thinking mercerized means “coated” or “waxed.” Nothing is added; the cellulose itself is swollen and rearranged.
- Comparing a thin mercerized thread with a thick plain string and calling the string stronger. Compare per gram or match the sizes.

- Trying to reproduce the process with drain cleaner. Lye burns are serious; this is a museum-and-mill process, not a kitchen one.

Make it a game · Shine Line-Up. Collect eight threads and yarns: sewing threads, embroidery floss, perle cotton, string, yarn. Lay them under a lamp. Each player ranks them from most to least luster and guesses which are mercerized. Then read the labels. One point for each correct “mercerized” call; the best ranking of the shiny end earns two more.

1.4 FLAX AND FINE LINEN

OBJECTIVES

- Describe how flax becomes linen: pulling, retting, breaking, scutching, hackling and spinning.
- Explain linen's properties (strength, coolness, luster, wrinkling, quick drying) from its fiber structure.
- Measure wrinkle recovery and drying rate and compare linen with cotton.

Warm-up. Find something made of linen in your house (a tea towel, a tablecloth, a summer shirt; check the label). Crush a corner of it in your fist for 30 seconds and do the same to a cotton towel. Open both and compare the creases.

WATCH

How is Belgian linen made? From flax to linen.

[Libeco Belgian Linen](#) · 9:38

<https://www.youtube.com/watch?v=ZrZZefkohE>

WHEN TO WATCH

After “How they figured it out.” Count the stages from the field to the yarn, and watch how the woody stem falls away during breaking and scutching.

BACKUP VIDEO

How to Make Linen from Flax

[George Washington's Mount Vernon](#) · 2:35

<https://www.youtube.com/watch?v=7Eec859dAhg>

A short look at the same steps done by hand at George Washington's Mount Vernon.

KEY TERMS

bast fiber

A fiber from the inner bark of a plant's stem: flax, hemp, jute, ramie, kenaf.

scutching

Beating broken flax stems with a wooden blade to knock away the woody bits (shives) and free the fiber.

line and tow

Line: the long, parallel flax fibers spun into fine linen. Tow: the short fibers combed out, spun into coarser yarn.

retting

Letting bacteria and fungi rot the pectin that glues fiber bundles to the stem, either by dew on the field for weeks or in water for days.

hackling

Combing scutched flax through sets of metal pins to separate long line fibers from short, tangled tow.

wrinkle recovery

How far a creased fabric springs back toward flat, measured as an angle (180° is complete recovery).

CORE IDEAS

The story. Linen is the oldest cloth with a long written history. Egyptian tombs held linen woven so fine that later weavers marveled at it, and mummies were wrapped in hundreds of yards of it. Pharaoh arrayed Joseph in vestures of fine linen (Genesis 41:42), and the curtains of the tabernacle were of fine twined linen (Exodus 26:1). The capable woman of Proverbs “seeketh wool, and flax.” For most of history, in Europe and in colonial America, every farm family grew a flax patch, and turning its stems into shirts and sheets was a year's work for the household.

How they figured it out. Flax fiber lies in bundles just under the stem's skin, glued by pectin to a woody core. The flax is pulled up by the roots, not cut, to keep every inch of fiber. Then comes *retting*: spread on the grass for weeks, or sunk in a pond or slow stream for days, until bacteria and molds dissolve the pectin. The dried stems are crushed in a *flax brake* to snap the woody core, *scutched* with a wooden knife over a board to beat the woody bits away, and *hackled* through combs of iron pins. What comes out is *line*, long, glossy

fibers often 20 inches or more, and *tow*, the short tangles. Line was spun wet on a flax wheel into fine thread; tow went into coarse sacking and work clothes.

The fabric science. Flax is cellulose like cotton, but the plant builds it differently. A flax “fiber” is a bundle of long, slender cells, each only an inch or two long, cemented together. Its cellulose is highly crystalline and its chains lie nearly parallel to the fiber's length. That makes linen very strong (stronger than cotton, and stronger still when wet), lustrous (smooth, straight, reflective fibers), and stiff, with very little stretch, only about two or three percent before breaking. Because the fiber cannot stretch, a crease bends it past the point of springing back: linen wrinkles more than any common fiber. Its high moisture regain (about 12 percent) and good heat conduction let it pull warmth and sweat away from the skin, so it feels cool and dries quickly.

Look closely. Under a 10× lens, linen yarn shows thick-and-thin places (slubs), because flax bundles split unevenly. A good microscope shows faint cross-marks along each fiber, called nodes, a little like the joints of bamboo. These are the clues an expert uses to tell linen from cotton when the label is gone.

The studio lab. You will measure two properties that make linen famous: its wrinkling and its quick drying. A folded strip held under a weight for five minutes, then released, shows how far each fabric recovers; a soaked swatch weighed every five minutes shows how fast each gives up water.

PICTURE STUDY



Flax Barn at Laren, Max Liebermann, 1887 · Oil on canvas · Alte Nationalgalerie, Berlin

Image: [Wikimedia Commons](#), public domain

Max Liebermann painted this flax barn in the Dutch village of Laren after several visits. Women spin flax walking backward down the long room, drawing fiber from bundles at their waists, while children at the far end turn the wheels that twist the yarn. It shows a whole village's work on one material, at a time when hand-spun linen was disappearing elsewhere.

Look closely

- Find the bundles of flax fiber. What color are they, and does it look like line or tow?
- Follow a woman walking backward down the room. What is she doing with the flax at her waist? (Rope and coarse yarn were spun this way, walking away from a turning wheel.)
- Find the seated figures at the wheels on the left. What job do they have, and why would it matter that they turn at a steady speed?
- Look at the light. Why would spinners want a long room with windows along one side?

Talk about it

1. How many people can you count, and what does that tell you about how much labor one length of linen yarn required?
2. Liebermann painted ordinary work as worth looking at. What details show he watched closely rather than inventing the scene?
3. If one spinner in this room walked about 20 yards to spin one length, how could you estimate how far she walked in a day?

Safety first. Wet floors are slippery: dry swatches on a rack or line, not on the floor, and wipe up drips. Use only the weights you need for the crease test and set them down gently.

STUDIO LAB

Linen and Cotton: Crease and Dry

Question: Is linen really slower to recover from wrinkles and faster to dry than cotton? You will measure wrinkle recovery angles and drying curves for linen and cotton fabrics of similar weight, with polyester as a comparison.

You will need

- Linen, cotton and polyester woven fabric of similar weight (a linen tea towel, a cotton sheet or shirt, a polyester shirt)
- A protractor, a ruler, scissors and a 500 g weight (a full 16-oz can works)
- Two index cards, a timer and the 0.1 g scale
- A drying rack or a line and clothespins, and a bowl of water

CREASE AND DRYING TEST SPECIMENS

Finished size: 3 crease strips and 1 drying square per fabric · About 20 minutes to cut and label

Fabric and notions

- Linen, cotton and polyester woven fabric, about 8 × 8 in (20 × 20 cm) of each
- Masking tape and a fine marker for labels
- Index cards

How to make it

1. Press each fabric flat with a warm iron set for its fiber, using a press cloth on the polyester, and let it cool.
2. From each fabric cut three crease strips, 1 × 3 in (2.5 × 7.5 cm), with the long side along the lengthwise grain (parallel to the selvage).
3. From each fabric cut one drying square, 4 × 4 in (10 × 10 cm).
4. Label every piece on a tab of masking tape: fiber and strip number.
5. Stack each set between index cards so they stay flat and dry until testing.

Fabric check: Choose plain-weave fabrics of similar thickness so the fiber, not the weave, is the main difference. Check labels: a “linen look” fabric may be polyester or a blend. If you have no pure linen, a thrift-store linen napkin or shirt is easy to find. Prewash all three so finishes do not affect the drying test.

Steps

1. **Hypothesis.** Predict the ranking of the three fabrics for wrinkle recovery and for drying speed.
2. **Crease test.** Fold a strip in half crosswise, lay it between index cards, and set the 500 g weight on the fold for 5 minutes.
3. Remove the weight and lift the strip so it hangs over the edge of a table with one half flat on the table. After 5 minutes, measure the angle between the two halves with the protractor. Record it.
4. Repeat for all three strips of each fabric; find the mean recovery angle and percent recovery.
5. **Drying test.** Weigh each drying square dry. Soak all three for 5 minutes, lift out, let them drip for 30 seconds without squeezing, and weigh each wet.
6. Hang them side by side away from direct sun. Weigh each every 5 minutes for 40 minutes, recording every reading.
7. Calculate percent water remaining at each time and draw all three drying curves on one graph (time across, percent water remaining up).
8. **Conclude.** Rank the fabrics for each property. Did linen behave as the lesson predicted?
9. **Repeat round.** Iron a creased linen strip with steam and test it again. Then repeat the crease test with the weight on for 30 minutes instead of 5. What changes?

Tips

- Hold the hanging strip by its flat half only; touching the fold changes the angle.

- If the scale drifts, re-zero it before each weighing.
- Older textile labs use a standard version of this crease test with a special angle dial; your protractor version measures the same idea.

Check your work

- ☐ I cut every strip on the lengthwise grain and labeled every specimen.
- ☐ I measured three crease strips per fabric and reported means.
- ☐ I graphed three drying curves on one set of axes and drew a conclusion from them.

LAB NOTEBOOK

1. Draw a cross-section of a flax stem: skin, fiber bundles, woody core, hollow center. Label which parts retting, breaking and scutching remove.
2. Tape a crease strip of each fabric on the page at its recovered angle and write the angle beside it.
3. Paste your drying graph and write two sentences explaining linen's curve with the words crystalline and regain.

KEY FORMULAS

$$\text{wrinkle recovery} = \frac{\text{recovery angle}}{180^\circ} \times 100\%$$

$$\text{wrinkle recovery} = 180^\circ - \text{recovery angle} \times 100\%$$

$$\text{water remaining} = \frac{m_t - m_{\text{dry}}}{m_{\text{wet}} - m_{\text{dry}}} \times 100\%$$

$$\text{water remaining} = m_{\text{wet}} - m_{\text{dry}} \times 100\%$$

From history. In the 1700s and 1800s the north of Ireland became one of the great linen regions of the world, and Belfast's mills earned it the nickname "Linenopolis." Irish linen, bleached in the sun on wide grass fields called bleach greens, was famous for its whiteness and was exported around the world.

WORKED EXAMPLES

Example 1. After the crease test, linen opens to 75°, cotton to 95° and polyester to 160°. Express each as percent recovery.

Show solution

1. Linen: $\frac{75^\circ}{180^\circ} \times 100\% = 41.7\%$
2. Cotton: $\frac{95^\circ}{180^\circ} \times 100\% = 52.8\%$
3. Polyester: $\frac{160^\circ}{180^\circ} \times 100\% = 88.9\%$

Answer: About 42%, 53% and 89%: linen keeps its creases most, polyester springs back best.

Example 2. A linen swatch weighs 15.0 g dry and 32.0 g wet. After 20 minutes on the line it weighs 22.8 g. What percent of its water remains, and what was its average drying rate?

Show solution

1. Water at start: $32.0 - 15.0 = 17.0$ g; at 20 min: $22.8 - 15.0 = 7.8$ g
2. Remaining: $\frac{7.8 \text{ g}}{17.0 \text{ g}} \times 100\% = 45.9\%$
3. Rate: $\frac{17.0 - 7.8 \text{ g}}{20 \text{ min}} = 0.46 \text{ g/min}$

Answer: About 46% of the water remained; it lost about 0.46 g of water per minute.

Example 3. A hackler combs 10.0 kg of scutched flax and gets 6.0 kg of line, 3.6 kg of tow and the rest waste. Find each as a percent.

Show solution

1. Waste: $10.0 - 6.0 - 3.6 = 0.4$ kg $10.0 - 6.0 - 3.6 = 0.4$ kg.

2. Line $6.0/10.0 = 60\%$ $6.0/10.0 = 60\%$; tow $3.6/10.0 = 36\%$ $3.6/10.0 = 36\%$; waste 4% 4% .

Answer: 60% line, 36% tow, 4% waste.

PRACTICE

1. **Easy** Put in order: hackling, retting, pulling, scutching, breaking, spinning.

Show answer

Pulling, retting, breaking, scutching, hackling, spinning.

2. **Easy** What substance does retting dissolve?

Show answer

Pectin, the glue binding the fiber bundles to the stem.

3. **Easy** Why is flax pulled rather than cut?

Show answer

To keep the full length of fiber, which runs into the root.

4. **Medium** A fabric recovers to 120° . Find its percent recovery.

Show answer

$120/180 \times 100\% = 66.7\%$ $120/180 \times 100\% = 66.7\%$

5. **Medium** Explain in two sentences why linen wrinkles so readily.

Show answer

Its highly crystalline, parallel chains make a stiff fiber that stretches only 2–3% before breaking. A sharp fold strains it beyond its elastic range, so it stays bent.

6. **Medium** Why does linen feel cool on a hot day?

Show answer

It absorbs moisture readily (about 12% regain) and conducts heat well, drawing heat and sweat away from the skin, and it dries quickly.

7. **Medium** A cotton swatch is 14.0 g dry and 35.0 g wet; after 20 min it weighs 27.4 g. What percent of its water remains?

Show answer

$(27.4 - 14.0)/(35.0 - 14.0) = 13.4/21.0 \approx 63.8\%$ $(27.4 - 14.0)/(35.0 - 14.0) = 13.4/21.0 \approx 63.8\%$

8. **Hard** Compare the cotton result in problem 7 with linen's 45.9% in worked example 2. Which dried faster, and name two variables that must be equal for the comparison to be fair.

Show answer

Linen dried faster (less water remaining). Fair test: same swatch size and fabric weight, same wetting and wringing, same drying spot (air, sun, humidity).

9. **Hard** A family grows enough flax for 8 kg of scutched fiber. At 60% line, how much line do they get, and how many 150 g shirts' worth of linen yarn, if spinning and weaving lose 20%?

Show answer

Line 4.8 kg 4.8 kg; usable $4.8 \times 0.8 = 3.84$ kg $4.8 \times 0.8 = 3.84$ kg; $3,840/150 = 25.6$, $3,840/150 = 25.6$, about 25 shirts.

10. **Hard** Why do experts look for nodes and slubs to tell linen from cotton?

Show answer

Flax fiber bundles show cross-marks (nodes) and split unevenly into thick-and-thin yarn (slubs); cotton is a smooth twisted ribbon that spins into more even yarn.

11. **Challenge** Linen is stronger wet, wrinkles badly and dries fast. Choose the best and worst everyday uses for linen and defend each in two sentences.

Show answer

Best: kitchen towels or summer shirts; strong when wet, lint-free, absorbent and quick-drying, and wrinkles do not matter in a towel. Worst: travel clothes meant to look pressed; linen creases in a suitcase and needs ironing. (Other well-defended answers earn credit.)

COMMON MISTAKES

- Thinking wrinkles mean low quality. Linen's creases come from the same stiff, crystalline structure that makes it strong and lustrous.
- Cutting test strips on the bias. Bias strips stretch and twist; cut every strip on the lengthwise grain.
- Wringing some swatches harder than others in the drying test. Drip, do not squeeze, so each starts with its natural water load.

Make it a game • Crumple Court. Each player brings three mystery fabrics with labels hidden. Everyone crumples each in a fist for 20 seconds, then opens it and judges: linen, cotton, wool or synthetic. Reveal labels. One point per right call; two points for spotting a linen-look polyester. The loser irons the winner's creased swatches.

Scripture. “She seeketh wool, and flax, and worketh willingly with her hands.” (Proverbs 31:13, KJV)

The two great fibers of the ancient household appear side by side. Seeking flax meant a year of pulling, retting, scutching and spinning, and Scripture calls that willing handwork a mark of a capable woman.

1.5 HEMP, JUTE, RAMIE AND THE BURN-AND-FEEL LAB

OBJECTIVES

- Name the main bast, leaf and seed fibers (hemp, jute, ramie, kenaf, sisal, abaca, coir, kapok) and a typical use for each.
- Carry out a safe burn test and describe how cellulose fibers burn, smell and leave ash, compared with protein and synthetic fibers.
- Identify unknown fibers by combining burn, feel and magnifier evidence, and calculate the fiber masses in a blend.

Warm-up. Find three ropes, cords or bags in the house or garage (a burlap sack, a jute twine, a nylon rope). Feel each with your eyes closed and describe its texture in one word. Which ones do you think came from plants?

WATCH

The Science of It: Fabric Burn Test

[Orlando Science Center](#) · 4:39

<https://www.youtube.com/watch?v=pW28ko4Mqlw>

WHEN TO WATCH

Before the lab, with your parent. Watch how science-center educators hold each specimen with tongs over a glass dish, with an extinguisher at hand, and how each fiber behaves as it nears the flame.

BACKUP VIDEO

Burn Testing for Fabric Identification

[Threads Sewing](#) · 2:41

<https://www.youtube.com/watch?v=xmKKvcpQujo>

A close-up burn test of several fabrics over a metal pan, for review just before your own lab.

KEY TERMS

hemp

A strong, coarse bast fiber long used for rope, canvas and sailcloth.

ramie

A lustrous, very strong bast fiber from a nettle-family plant, sometimes called China grass; hard to process and brittle when folded.

burn test

Identifying a fiber by how it approaches, burns in and leaves a flame, its smell, and its ash or bead. Done only with a parent beside you.

jute

A golden-brown bast fiber grown mostly in Bengal, used for burlap (hessian), sacks and twine; inexpensive but weak when wet and quick to yellow.

leaf and seed fibers

Leaf fibers (sisal, abaca or Manila hemp) come from long leaves and make rope; seed and fruit fibers include cotton, kapok and coir from coconut husks.

afterglow

A red glow that creeps along a cellulose fiber after the flame goes out.

CORE IDEAS

The story. For most of history the world's rope and heavy cloth came from bast and leaf fibers. Hemp ropes and canvas rigged sailing ships; colonial American towns had long *ropewalks*, buildings sometimes hundreds of yards long where workers walked backward twisting hemp into rope. In the 1800s jute from Bengal was shipped to Dundee in Scotland, where mills learned to soften the stiff fiber with whale oil and water so it could be spun, and Dundee became the jute capital of the world, weaving the burlap sacks that carried grain, coffee and cotton.

How they figured it out. Each plant gave up its fiber differently. Hemp and jute, like flax, are retted and stripped from their stalks; jute is retted for weeks in ponds and then stripped by hand. Ramie's fiber is so heavily gummed that it must be boiled with chemicals

(degummed) before it can be spun. Sisal and abaca are scraped from long leaves, and coir is soaked out of coconut husks. Kapok, the silky fluff from the seed pods of the kapok tree, is too smooth to spin but so light and water-shy that it once stuffed life jackets.

The fabric science. All of these are cellulose, with lignin (the woody stiffener) in the coarser ones. More lignin means a stiffer, rougher, weaker-when-wet fiber that yellows in sunlight; that is why jute is cheap and coarse while scoured ramie can look almost like silk. Because they are cellulose, they all behave alike in a flame: cellulose fibers ignite quickly, burn with a steady yellow flame, smell like burning paper or leaves, often keep an afterglow, and leave a small amount of soft, gray, feathery ash. Protein fibers (Unit 2) sputter, smell like burning hair and leave a crushable black bead; most synthetics (Unit 3) shrink away from the flame, melt, drip and leave a hard bead.

Telling them apart. A burn test says “cellulose” but cannot tell cotton from linen from hemp. For that, add other evidence. Feel: linen and ramie are cool, smooth and stiff; jute is harsh and hairy. Look: under 10× cotton is a twisted ribbon, bast fibers are straight bundles with nodes. Twist: when a single wet flax fiber dries it turns clockwise, and hemp counterclockwise, a classic test still used by fiber experts. Real identification means gathering several kinds of evidence and reasoning to the best answer, which is good practice for every kind of science.

Blends. Many fabrics mix fibers, and a burn test of a blend shows mixed behavior: a 50/50 cotton/polyester snippet burns, smells of paper and chemicals, and leaves both ash and hard beads. The fiber-content label, required by law in the United States (Unit 6), gives the percentages by weight, which lets you calculate how many grams of each fiber are in a garment.

The studio lab. With a parent beside you, you will burn-test known cellulose fibers, then a wool and a polyester control, recording each behavior in a chart. Then you will identify three unknowns using burn, feel and magnifier evidence together. Your results become the first pages of your unit project, a plant-fiber identification kit.

PICTURE STUDY



Breaking Hemp (Das Hanfbrechen), Albert Kappis, 1873 · Oil on canvas · Image from Wikimedia Commons (public domain)

Image: [Wikimedia Commons](#), public domain

Albert Kappis painted the farm life of southern Germany. Here a village works its hemp after retting: the stalks are dried over a smoking pit so they will snap cleanly, then crushed in wooden brakes so the woody core can be beaten away from the fiber. It was hard, dusty, social work, done by neighbors together in autumn.

Look closely

- Find the smoking pit at the left. Why would the stalks be dried with heat before breaking?
- Look at the bundles in the workers' hands. Which part of the stalk would break and fall, and which part would stay whole?
- Find the dust or chaff in the air or on the ground. What is it made of?
- Count the workers. Who is breaking, who is carrying, and who is gathering?

Talk about it

1. This is the same process you studied for flax. Which steps came before this moment, and which come after?

2. Why might a village do this together outdoors rather than one family at a time in a barn?
3. If you had to break 100 bundles by hand, what would you want to know about the retting before you started?

Safety first. Burn tests are done **only with a parent beside you**: a ½-inch snippet held in tweezers or hemostats over a metal pan or the sink, a cup of water at hand, hair tied back, sleeves pushed up, away from curtains and paper. Use a candle or long lighter, never a gas stove, and keep synthetic snippets well away from your face because they melt and drip. Do not burn treated or flame-resistant fabrics, and air out the room afterward.

STUDIO LAB

The Burn-and-Feel Identification Lab

Question: Can you identify unknown fibers reliably by combining burn, feel and magnifier evidence? You will build a reference chart from known fibers, then challenge yourself with unknowns a parent prepares.

You will need

- Known snippets, about ½ × 2 in each: cotton, linen, jute (burlap or twine), rayon if available, plus wool and polyester as controls
- Three unknowns, chosen and labeled A, B and C by a parent
- Tweezers or hemostats, a metal baking pan or the sink, a cup of water and a candle in a holder
- The 10× magnifier, black and white paper, and a small dish of water
- Your lab notebook with a burn-test chart

FIBER IDENTIFICATION CARD

Finished size: One 4 × 6 in card per fiber · About 10 minutes per card

Fabric and notions

- 4 × 6 in index cards or cardstock, one per fiber
- A 1 × 2 in swatch of each fabric, a few loose fibers or yarns from it, and the burn residue
- Clear tape, a small zip-top bag for ash or beads, and a fine pen

How to make it

1. Write the fiber's name and its source (plant, animal, people-made) across the top of the card.
2. Tape the fabric swatch at the upper left and a few loose fibers under clear tape beside it.
3. Seal the burn residue in a tiny bag and tape it below the swatch.
4. Fill in four lines: Burn (approach, in flame, out of flame), Smell, Residue, Under 10×.
5. Add two lines for Feel and Best uses, and date the card.
6. File the cards in a box or ring them together; this is the start of your unit project kit.

Fabric check: Use fabrics whose labels you trust for the known set: a cotton dish towel, a linen napkin, a burlap bag, a wool sock and a polyester shirt are reliable. Avoid fabrics treated for flame resistance (children's sleepwear, some upholstery) and anything with a shiny coating. Wool-sensitive students can handle wool with tweezers only.

Steps

1. **Set up** with your parent: metal pan in the sink or on a clear counter, candle in a stable holder, water at hand, hair tied back, nothing flammable nearby.
2. **Hypothesis.** Before burning, predict for each known fiber whether it will burn, melt or sputter.
3. Hold a known snippet in tweezers and move it slowly toward the side of the flame. Record: does it shrink away, melt, or ignite as it approaches?
4. Put the tip into the flame for 2 seconds. Record the flame color and whether it burns steadily or sputters.
5. Pull it out. Does it keep burning, go out, or glow? Blow it out if it keeps burning, drop it in the pan, and smell the smoke by wafting it toward you with your hand.

6. Let the residue cool for a minute, then rub it between your fingers. Soft ash, crushable black bead or hard bead? Record and save it.
7. Repeat for every known fiber, then examine each under 10× and record what you see and feel.
8. **Unknowns.** Test A, B and C the same way, adding magnifier, feel and (for bast fibers) the drying-twist test. Write your identification and your reasons for each.
9. Check your answers with your parent's key. For any you missed, find the test that misled you.
10. **Clean up.** Run water over the pan, blow out and store the candle, ventilate the room, and make the identification cards.

Tips

- Waft, do not sniff directly over the flame. Smells are clues, not something to breathe deeply.
- Test several snippets of each fiber: one snippet can mislead.
- Rayon will fool you in a burn test; it is cellulose too. That is a good lesson, not a failure.

Check your work

- ☐ I followed every safety step with my parent beside me.
- ☐ I recorded approach, flame, removal, smell and residue for every snippet.
- ☐ I identified the unknowns with at least two kinds of evidence each and explained my reasoning.

LAB NOTEBOOK

1. Make a three-column comparison chart, cellulose, protein, synthetic, with rows for approaching the flame, in the flame, out of the flame, smell and residue.
2. Tape in a finished identification card for each known fiber.
3. For each unknown, write a short paragraph of reasoning: the evidence, what it ruled out, and your conclusion.

KEY FORMULAS

$$m_{\text{fiber}} = m_{\text{garment}} \times \frac{\text{fiber percent}}{100}$$

$$m_{\text{fiber}} = m_{\text{garment}} \times 100 \text{ fiber percent}$$

$$g/m^2 \approx oz/yd^2 \times 33.9$$

$$g/m^2 \approx oz/yd^2 \times 33.9$$

From history. Abaca, from a banana-family plant in the Philippines, was called Manila hemp, though it is no relation to true hemp. Its rope resists salt water so well that it was prized for ships' hawsers, and a strong paper made from it gave "manila envelopes" and "manila folders" their name.

WORKED EXAMPLES

Example 1. A tablecloth weighs 440 g and its label reads 55% linen, 45% cotton. How many grams of each fiber does it contain?

Show solution

1. Linen: $440 \text{ g} \times 0.55 = 242 \text{ g}$ $440 \text{ g} \times 0.55 = 242 \text{ g}$.
2. Cotton: $440 \text{ g} \times 0.45 = 198 \text{ g}$ $440 \text{ g} \times 0.45 = 198 \text{ g}$.
3. Check: $242 + 198 = 440 \text{ g}$ $242 + 198 = 440 \text{ g}$.

Answer: 242 g linen and 198 g cotton.

Example 2. Burlap is sold as 10-oz (10 oz/yd²). Convert to g/m², and find the mass of a 36 × 24 in feed-sack panel.

Show solution

1. Weight: $10 \times 33.9 = 339 \text{ g/m}^2$ $10 \times 33.9 = 339 \text{ g/m}^2$.
2. Area: $36 \times 24 = 864 \text{ in}^2$ $36 \times 24 = 864 \text{ in}^2$; one square yard is $36 \times 36 = 1,296 \text{ in}^2$ $36 \times 36 = 1,296 \text{ in}^2$, so the panel is $864/1,296 = 0.667 \text{ yd}^2$ $864/1,296 = 0.667 \text{ yd}^2$.
3. Mass: $0.667 \text{ yd}^2 \times 10 \text{ oz/yd}^2 = 6.67 \text{ oz} \approx 189 \text{ g}$ $0.667 \text{ yd}^2 \times 10 \text{ oz/yd}^2 = 6.67 \text{ oz} \approx 189 \text{ g}$.

Answer: 339 g/m²; the panel weighs about 6.7 oz (189 g).

Example 3. Reasoning from evidence. Unknown C ignites quickly, smells like paper, leaves soft gray ash and shows an afterglow. Under 10× it is a straight bundle with cross-marks; it feels cool and stiff, and a damp single fiber turns clockwise as it dries. What is it?

Show solution

1. Burn behavior (quick ignition, paper smell, gray ash, afterglow) says cellulose; that rules out wool, silk and synthetics.
2. Straight bundles with nodes rule out cotton, whose fibers are twisted ribbons, and point to a bast fiber.
3. Cool, stiff hand fits linen or ramie; clockwise drying twist fits flax and not hemp.

Answer: Linen (flax). Each test alone was not enough; together they point to one answer.

PRACTICE

1. **Easy** Sort into bast, leaf or seed fiber: jute, sisal, cotton, ramie, abaca, kapok, hemp, coir.

Show answer

Bast: jute, ramie, hemp. Leaf: sisal, abaca. Seed or fruit: cotton, kapok, coir.

2. **Easy** Describe the smell and residue of a burning cellulose fiber.

Show answer

Burning paper or leaves; soft, gray, feathery ash, often with an afterglow.

3. **Easy** Which city became the world's jute capital in the 1800s?

Show answer

Dundee, Scotland.

4. **Medium** A 300 g shirt is 60% cotton, 40% polyester. Find the mass of each fiber.

Show answer

Cotton 180 g 180 g, polyester 120 g 120 g.

5. **Medium** Convert 7 oz/yd² to g/m².

Show answer

$7 \times 33.9 \approx 237 \text{ g/m}^2$ $7 \times 33.9 \approx 237 \text{ g/m}^2$

6. **Medium** Why can a burn test not tell cotton from linen?

Show answer

Both are cellulose and burn the same way; you need magnifier, feel or twist evidence.

7. **Medium** Why does jute yellow in sunlight and feel harsh, while scoured ramie can look like silk?

Show answer

Jute carries much lignin, which yellows in light and stiffens the fiber; degummed ramie is nearly pure, highly oriented cellulose that is smooth and lustrous.

8. **Hard** A snippet burns with a paper smell and gray ash, but also leaves a few hard, dark beads. What is it most likely, and how would you check?

Show answer

A blend of a cellulose fiber with a synthetic such as polyester. Check the label, or separate warp and weft yarns and burn each alone.

9. **Hard** A rope is 70% sisal, 30% polypropylene and weighs 2.4 kg for 50 m. Find the sisal mass per meter.

Show answer

$$2.4 \times 0.70 = 1.68 \text{ kg}; 2.4 \times 0.70 = 1.68 \text{ kg}; 1,680/50 = 33.6 \text{ g/m}; 1,680/50 = 33.6 \text{ g/m}.$$

10. **Hard** A burlap bag of 12 oz/yd² is cut from 1.25 yd² of cloth. Find its mass in grams.

Show answer

$$12 \times 1.25 = 15 \text{ oz}; 12 \times 1.25 = 15 \text{ oz}; 15 \times 28.35 \approx 425 \text{ g}; 15 \times 28.35 \approx 425 \text{ g}.$$

11. **Challenge** Explain why a good identification uses several independent tests, using the idea of ruling out possibilities. Give an example where one test alone would mislead.

Show answer

Each test narrows the list; agreement among independent tests makes the answer reliable. Example: rayon burns exactly like cotton, so a burn test alone would call a rayon blouse cotton; its smooth, lustrous, striated fibers under magnification and its weakness when wet reveal it.

COMMON MISTAKES

- Burning a big piece of fabric. A ½-inch snippet tells you everything and stays safe.
- Trusting one test. A burn test separates the families; feel, magnifier and labels separate the fibers.
- Leaning in to smell. Waft the smoke toward you with your hand, at arm's length.

Make it a game · Blindfold Fiber Court. A parent hands each blindfolded player five swatches one at a time: cotton, linen, wool, silk or polyester, and burlap. The player has 15 seconds to feel and name the fiber. One point per correct name, two for naming linen. Then switch roles and see whether the parent's fingers are as good as the student's.

UNIT 1 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **7 pts**
Describe how a cotton fiber grows from the seed, and why it dries into a flat, twisted ribbon.
2. **7 pts**
How did Whitney's gin separate lint from seed, and what improvement did Hodgen Holmes patent in 1796?
3. **7 pts**
In three or four sentences, tell honestly how the cotton gin changed the American South.
4. **7 pts**
A gin turns 3,000 lb of seed cotton into 1,080 lb of lint. Find the turnout, and how many 480-lb bales the lint makes.
5. **7 pts**
Convert a staple of 38/32 inch to inches and millimeters. Is it upland or extra-long staple?
6. **7 pts**
Explain, using hydrogen bonds and amorphous regions, why cotton absorbs water and wrinkles.
7. **7 pts**
A swatch weighs 24.0 g bone-dry and 26.0 g conditioned. Find the moisture regain and the moisture content.
8. **6 pts**
Dry cotton threads broke at a mean of 1,200 g; wet ones at 1,390 g. Find the percent change and state whether it agrees with the lesson.
9. **7 pts**
What did John Mercer discover in 1844, what did Horace Lowe add, and what three changes does mercerization make to cotton?
10. **6 pts**
A 1,500 kg bath contains 300 kg of NaOH. Find its concentration, and the mass of water to add to dilute it to 18%.
11. **6 pts**
List the steps from flax plant to linen yarn and say what each does.
12. **6 pts**
A creased fabric recovers to 81°. Find its percent recovery, and say which fiber from this unit it most likely is.
13. **6 pts**
A 640 g bedspread is 65% cotton and 35% linen. How many grams of each fiber does it contain?
14. **7 pts**
Describe the burn behavior of cellulose, protein and most synthetic fibers (approach, flame, smell, residue).
15. **7 pts**
Short essay (5–7 sentences): A friend says natural fibers are always better than synthetics. Using what you learned about cotton and linen, write a fair answer that names real strengths and real weaknesses of plant fibers.

UNIT PROJECT: A PLANT-FIBER IDENTIFICATION KIT

Build a labeled reference kit of plant fibers that you could hand to a younger student or a friend: at least eight identification cards (cotton, linen, jute or hemp, ramie or sisal if you can find them, rayon, and at least two plant-fiber blends), each with a fabric swatch, loose fibers, burn residue, magnifier notes, feel and best uses.

Add a one-page summary chart comparing the plant fibers' strengths and weaknesses, your staple-length, wet-strength, mercerization and linen data from the unit labs in one table, and a short written key explaining how to identify an unknown fiber step by step.

LOOK FOR	WHAT IT MEANS
Safety	Every burn test was done with a parent beside you, following each safety step, and the kit says so on its first page.
Accurate identification	Every card is correctly labeled, with burn, smell, residue, magnifier and feel evidence that fits the fiber.
Data and math	The summary table reports the unit's lab results with units, means and ranges, and the calculations are correct.
Clarity and craft	Cards are neat, consistent and durable, and the key could be followed by someone who did not take this course.
Honest records	Mistakes, surprises and repeated tests are reported, not hidden.

ANSWER KEY

1. Each fiber is a single seed-hair cell: it elongates for about three weeks, then thickens its wall with layers of cellulose. When the boll opens and it dries, the hollow lumen collapses and the fiber flattens and twists (convolutions).
2. Wire teeth on a turning cylinder pulled the lint through slots too narrow for the seeds; a brush cylinder cleared the teeth. Holmes replaced the wire teeth with circular saws.
3. The gin made short-staple cotton cheap to clean, so cotton planting spread across the Deep South to supply the mills. Planting and picking were still hand work, so planters bought more enslaved people, and slavery grew from about 700,000 people in 1790 to nearly 4 million by 1860. The invention that saved labor in one step multiplied forced labor in the others.
4. $1,080/3,000 \times 100\% = 36\%$; $1,080/3,000 \times 100\% = 36\%$; $1,080/480 = 2.25$; $1,080/480 = 2.25$ bales.
5. $38/32 = 1.1875$ in ≈ 30.2 mm; $38/32 = 1.1875$ in ≈ 30.2 mm; a long upland staple, short of extra-long ($1\frac{3}{8}$ in and up).
6. Each glucose unit has -OH groups that attract water; water enters the loosely packed amorphous regions. When the fabric is bent, water-loosened hydrogen bonds break and re-form with the chains in bent positions, holding a wrinkle.
7. $\text{Regain } 2.0/24.0 \times 100\% = 8.3\%$; $2.0/24.0 \times 100\% = 8.3\%$; $\text{content } 2.0/26.0 \times 100\% = 7.7\%$; $2.0/26.0 \times 100\% = 7.7\%$.
8. $190/1,200 \times 100\% \approx 15.8\%$; $190/1,200 \times 100\% \approx 15.8\%$ stronger wet; it agrees with cotton's usual 10–20% wet gain.
9. Strong caustic soda swells cotton, making it shrink, thicken, strengthen and dye deeper. Lowe treated it under tension, which prevented shrinkage and gave luster. Results: luster, strength and dye uptake.
10. $300/1,500 = 20\%$; $300/1,500 = 20\%$; new total $300/0.18 \approx 1,667$ kg; $300/0.18 \approx 1,667$ kg, so add about 167 kg of water.
11. Pulling (keeps full fiber length), retting (bacteria and molds dissolve pectin), breaking (snaps the woody core), scutching (beats away shives), hackling (separates line from tow), spinning (twists fiber into yarn).
12. $81/180 \times 100\% = 45\%$; $81/180 \times 100\% = 45\%$; low recovery suggests linen.
13. Cotton 416 g; linen 224 g.
14. Cellulose: ignites quickly, steady yellow flame, paper smell, afterglow, soft gray ash. Protein: curls and sputters, self-extinguishes, burning-hair smell, crushable black bead. Synthetics: shrink and melt on approach, drip, chemical smell, hard bead.
15. A good answer credits plant fibers with absorbency, comfort, coolness, wet strength and easy pressing, and names their weaknesses honestly: wrinkling, shrinking, slow drying (cotton), stiffness (linen), mildew, and the labor and history behind them. It notes that the best fiber depends on the job and that synthetics have real strengths of their own (Unit 3).

FIBERS FROM ANIMALS

Plant fibers are built from a sugar polymer; animal fibers are built from proteins. Wool, mohair, cashmere, alpaca and camel hair are keratin, the same family of protein as your own hair and fingernails, coiled into springs, cross-linked by sulfur bridges and wrapped in overlapping scales. Silk is fibroin, a protein the silkworm spins into a single shining filament nearly a kilometer long. These structures explain everything about how animal fibers behave: why wool keeps you warm when damp and springs back from wrinkles, why a wool sweater can shrink to doll size in a hot wash, why silk shimmers and why chlorine bleach destroys both.

The stories take you from Gideon's dew-soaked fleece to the shearing shed and the wool classer's table, from the felting tubs of the old fulling mills to the goat herds of the high mountains, and from the silkworm on its mulberry leaf to the monks who carried silkworm eggs to Constantinople. In the labs you will weigh the water wool pulls from humid air, scour a greasy fleece and calculate its clean yield, shrink wool on purpose and measure it, compare the warmth of specialty fibers, and burn-test protein fibers to complete your animal-fiber pages of the identification kit.

PREREQUISITES

- Unit 1: moisture regain, percent change and the burn test
- A scale reading 0.1 g, a thermometer and a timer
- A parent available for the Lesson 2.5 burn and bleach tests

MASTERY CHECKLIST

- ☐ I can describe keratin and fibroin and explain how scales, crimp, cross-links and crystalline order give wool and silk their properties.
- ☐ I can calculate moisture regain, clean yield, shrinkage in length, width and area, and cooling rates.
- ☐ I can explain why wool felts, how fulling and superwash treatments work, and how to wash wool so it does not shrink.
- ☐ I can compare mohair, cashmere, alpaca and camel hair with wool fairly.
- ☐ I can tell the history of silk, from sericulture in China to Justinian's monks, separating legend from record.
- ☐ I can identify protein fibers by burn test and explain how to care for them.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **American Sheep Industry Association**: Free. The U.S. sheep and wool producers' association, with plain explanations of wool grades, micron and the wool year.
- **A few ounces of wool roving and a raw fleece sample**: Craft stores sell wool roving for felting; local shepherds and fiber festivals sell small raw-fleece samples cheaply. Lesson 2.2 needs a greasy lock or two.
- **A thrift-store 100% wool sweater (not superwash)**: The best felting lab material there is, and the shrunken fabric makes mittens or a pot holder afterward.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

2.1 Keratin and Gideon's Fleece	3 sessions of 50 minutes
2.2 From Shearing Shed to Micron Count	3 sessions of 50 minutes
2.3 Felting and Shrinkage: Wool's Scales at Work	3 sessions of 50 minutes
2.4 Mohair, Cashmere, Alpaca and Camel	3 sessions of 50 minutes
2.5 Silk: Fibroin, the Silkworm and the Silk Road	3 sessions of 50 minutes

2.1 KERATIN AND GIDEON'S FLEECE

OBJECTIVES

- Describe the structure of a wool fiber: cuticle scales, cortex, crimp, and keratin's coiled chains and sulfur cross-links.
- Explain why wool absorbs water vapor, stays warm when damp and springs back from wrinkles.
- Measure and compare moisture regain of wool, cotton and polyester, and estimate the water in Gideon's fleece.

Warm-up. Read Judges 6:36-40 aloud. Then hold a wool sock in one hand and a cotton sock in the other after both have spent a night in a cool bathroom or basement. Which feels damper? Write your guess about which actually holds more water.

WATCH

The Anatomy of Wool | TMI #3

ALTERKNIT · 8:31

<https://www.youtube.com/watch?v=r718L23Qazs>

WHEN TO WATCH

After “The fabric science.” Pause at the diagram of the fiber's layers and name each one before the narrator does.

Note: A knitting teacher's short lecture with clear diagrams of the wool fiber; a small channel, chosen for its accuracy.

BACKUP VIDEO

How Wool Is Made: From Farm to Fashion

Woolmark · 3:10

<https://www.youtube.com/watch?v=YwRbyTCqOQY>

A short animation of wool's journey from the farm through scouring, carding, combing and spinning.

KEY TERMS

keratin

The family of tough proteins that make wool, hair, horns and nails; long chains of amino acids coiled into helices and cross-linked by sulfur bridges.

disulfide bond

A strong sulfur-to-sulfur link between two chains of keratin, made by the amino acid cystine; it gives wool its springy resilience.

crimp

The natural wave of a wool fiber, caused by two kinds of cortex cells on opposite sides; it gives bulk, loft and stretch.

amino acid

One of about twenty small building-block molecules that link into protein chains.

cuticle scales

Thin overlapping cells covering a wool fiber like shingles on a roof, all pointing toward the tip.

lanolin

Wool wax, secreted by glands in the sheep's skin; it waterproofs the fleece and is refined from scoured wool for creams and ointments.

CORE IDEAS

The story. When God called Gideon to deliver Israel from the Midianites, Gideon asked for a sign. He laid a fleece of wool on the threshing floor overnight: if dew fell on the fleece only, and the ground stayed dry, he would know. “And it was so: for he rose up early on the morrow, and thrust the fleece together, and wringed the dew out of the fleece, a bowl full of water.” The next night he asked for the reverse, a dry fleece on wet ground, and that too was given. The miracle was God's; but the fleece was well chosen, for wool is the natural fiber that drinks the most water from the air.

How they figured it out. Shepherds and weavers knew wool's habits for thousands of years before anyone could see why. The microscope showed the scales in the 1600s and 1700s; X-ray studies in the 1930s, especially William Astbury's work at Leeds on wool

fibers, showed that keratin's chains are coiled into springs (helices) that straighten when the fiber is stretched and coil back when it is released. That discovery helped launch the science of protein structure itself.

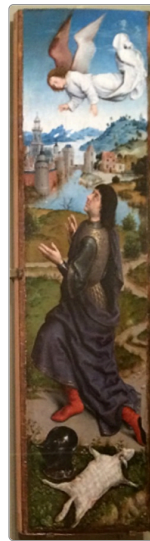
The fabric science. A wool fiber has three main parts. Outside, the *cuticle*: overlapping scales with a thin waxy skin that sheds liquid water. Inside, the *cortex*: millions of spindle-shaped cells, of two kinds arranged on opposite sides, which grow at slightly different rates and twist the fiber into its natural *crimp*. Coarse fibers may also have a hollow core, the medulla. The cortex is keratin: chains coiled into helices, tied to one another by sulfur bridges (disulfide bonds), salt links and hydrogen bonds. Stretch a dry wool fiber and the coils straighten, letting it lengthen by a quarter or more before breaking; release it, and the cross-links pull it back. That is why wool resists wrinkles and why a wool jacket hangs its creases out overnight.

Water and warmth. Keratin is full of water-loving groups. Wool's moisture regain is about 14 percent at ordinary room air, the highest of the common fibers, and in very humid air it can take up about a third of its own weight in water vapor before it feels wet to the touch. As the vapor binds inside the fiber it gives off heat, a small but real warming effect when you step from a dry house into cold, damp air. Meanwhile the crimped fibers hold still air between them, the real source of insulation. So wool keeps a shepherd warm in a wet fog when cotton would hang cold and clammy. Wool is also slow to ignite and tends to put itself out, because of its moisture and its nitrogen-rich protein; firefighters and sailors long valued it for that.

Lanolin. A sheep's skin oozes wax that coats the fleece and sheds rain. In a raw fleece the wax, sweat salts and dirt can make up a large share of the weight, often a third or more. Mills wash it out with warm water and detergent (scouring), and the recovered wax is refined into lanolin for creams and ointments. Lanolin is also why a raw lock feels sticky and why your hands come away soft after handling it.

The studio lab. You will dry equal masses of wool, cotton and polyester fiber, set them in humid air for a day, and weigh the water each one pulls in. Then you will use your own regain numbers to test Gideon's arithmetic: could one fleece really hold a bowl full of dew?

PICTURE STUDY



Gideon and the Fleece, Aelbrecht Bouts, c. 1500 · Oil on panel · Image from Wikimedia Commons (public domain)

Image: [Wikimedia Commons](#), public domain

Painters of the 1400s and 1500s loved Gideon's fleece as a sign of God's faithfulness. Aelbrecht Bouts, a Flemish painter of Leuven and son of the painter Dieric Bouts, shows Gideon in armor kneeling in prayer, an angel above him and the fleece lying on the ground before him.

Look closely

- Find the fleece. How did the painter show that it is a whole sheepskin of wool and not a cloth?
- Find the angel. How does the painter connect heaven and the fleece on the ground?
- Look at Gideon's posture and hands. Is he working, praying or waiting?
- Find his helmet on the ground. What does it tell you about who Gideon was and what he was about to do?

Talk about it

1. Why would Gideon choose a fleece, rather than a cloth or a bowl, for his sign?
2. If you were painting this scene, how would you show the bowl of water wrung out in the morning?
3. What does this picture say about how people of Bouts's time thought about wool and sheep?

Safety first. A low oven used to dry fiber samples stays at or below 200 °F (93 °C); use oven mitts and a parent's permission, and never leave the oven on unattended. Polyester fiberfill can soften if overheated, so keep samples on a baking sheet lined with parchment, away from the elements. Keep needles and pins counted in the pincushion.

STUDIO LAB

Gideon's Fleece Lab: Which Fiber Drinks the Air?

Question: When dry wool, cotton and polyester sit in the same humid air, how much water vapor does each absorb? You will dry, humidify and weigh three fibers, then use your results to test the arithmetic of Judges 6:38.

You will need

- About 10 g each of wool roving or a washed wool lock, cotton balls, and polyester fiberfill
- A scale reading 0.1 g, a baking sheet, parchment and a low oven (with permission)
- A large clear plastic tub with a lid, a bowl of warm water and a small rack or upside-down colander
- Three labeled mesh or paper cupcake liners, and a timer

Steps

1. **Hypothesis.** Rank the three fibers by how much water you think they will absorb, and guess wool's regain.
2. Dry the three samples on parchment in a 200 °F (93 °C) oven for 45 minutes. Remove with mitts, let them cool 2 minutes in a sealed bag, and weigh each at once. These are the dry masses.
3. Set the bowl of warm water in the bottom of the tub, the rack above it, and the three samples in their liners on the rack, not touching the water. Close the lid.
4. After 1 hour, weigh each sample quickly and return it. Repeat at 4 hours and 24 hours.
5. At 24 hours, feel each sample. Which feels damp, and does that match the weights?
6. Calculate regain at each time for each fiber and graph regain against time on one set of axes.
7. **Gideon's arithmetic.** Using your wool regain and a fleece of 3.5 kg, calculate the water a fleece could hold. Compare with a bowl.
8. **Conclude.** Rank the fibers by regain and by how damp they felt. Did weight and feel agree?
9. **Repeat round.** Move the samples to a dry, warm room for 4 hours and weigh again. Which gives up its water fastest?

Tips

- Weigh quickly: dried fiber starts picking up room moisture within seconds.
- If you have no oven, start from room-conditioned samples and measure the gain from room air to humid air instead; your numbers will be smaller but the ranking should hold.
- A thermometer pushed into the middle of the dry wool when it first goes into the humid tub may show a small rise of a degree or two: the heat of sorption.

Check your work

- ☐ I dried, humidified and weighed all three fibers the same way, recording every mass to 0.1 g.
- ☐ I graphed regain against time for three fibers.
- ☐ I used my own data to check Gideon's bowl of water.

LAB NOTEBOOK

1. Draw a wool fiber in cutaway: scales on the outside, cortex cells inside, the crimp wave along its length. Label each part.

2. Draw a short keratin chain as a coil with two sulfur bridges to a neighbor, then the same chain stretched straight. Write one sentence on what pulls it back.
3. Tape a pinch of each lab fiber beside your regain graph.

KEY FORMULAS

$$\text{regain} = \frac{m_{\text{humid}} - m_{\text{dry}}}{m_{\text{dry}}} \times 100\%$$

$$\text{regain} = \frac{m_{\text{humid}} - m_{\text{dry}}}{m_{\text{dry}}} \times 100\%$$

$$m_{\text{water}} = m_{\text{dry}} \times \frac{\text{regain}}{100}$$

$$m_{\text{water}} = m_{\text{dry}} \times 100\text{regain}$$

WORKED EXAMPLES

Example 1. After 24 hours in a humid tub, 10.0 g samples of oven-dried fiber weigh: wool 12.6 g, cotton 11.4 g, polyester 10.1 g. Find each regain.

Show solution

1. Wool: $\frac{12.6 - 10.0}{10.0} \times 100\% = 26\%$
2. Cotton: $\frac{11.4 - 10.0}{10.0} \times 100\% = 14\%$
3. Polyester: $\frac{10.1 - 10.0}{10.0} \times 100\% = 1\%$, within the scale's error.

Answer: Wool 26%, cotton 14%, polyester about one percent: in very humid air wool took up nearly twice cotton's water and polyester almost none.

Example 2. Gideon's check. A fleece weighs about 3.5 kg when clean and dry. If it reached a regain of 30% overnight, how much water could it hold, and how does that compare with a bowl holding about 1 liter?

Show solution

1. Water held: $3.5 \text{ kg} \times 0.30 = 1.05 \text{ kg}$
2. Water's density is about 1 kg per liter, so $1.05 \text{ kg} \approx 1.05 \text{ L}$
3. That is about one bowl. Dew lying on the outside of the fibers, not just inside them, would add more.

Answer: About a liter, a bowl full. The arithmetic fits the account.

Example 3. A raw fleece weighs 4.8 kg. Grease, suint and dirt make up 40% of the raw weight. How much clean wool and how much lanolin-bearing waste does scouring give?

Show solution

1. Waste: $4.8 \text{ kg} \times 0.40 = 1.92 \text{ kg}$
2. Clean wool: $4.8 - 1.92 = 2.88 \text{ kg}$

Answer: About 2.9 kg of clean wool and 1.9 kg of grease, dirt and salts washed out.

PRACTICE

1. **Easy** Name the three main parts of a wool fiber from outside in.

Show answer

Cuticle (scales), cortex, and (in coarse fibers) medulla.

2. **Easy** Which amino acid makes the sulfur cross-links in wool?

Show answer

Cystine (disulfide bonds).

3. **Easy** Read Judges 6:38. What did Gideon wring from the fleece?

Show answer

The dew: a bowl full of water.

4. **Medium** A 15.0 g dry wool sample weighs 17.1 g after conditioning. Find its regain.

Show answer

$$2.1/15.0 \times 100\% = 14\% \quad 2.1/15.0 \times 100\% = 14\%$$

5. **Medium** A 500 g dry wool blanket is at 15% regain. How much water does it hold?

Show answer

$$500 \times 0.15 = 75 \text{ g} \quad 500 \times 0.15 = 75 \text{ g}$$

6. **Medium** Explain why a wool jacket loses its wrinkles hanging overnight while a linen one does not.

Show answer

Wool's coiled keratin, tied by cross-links, stretches and springs back elastically; linen's stiff, crystalline cellulose barely stretches and stays bent.

7. **Medium** What causes crimp?

Show answer

Two kinds of cortex cells on opposite sides of the fiber grow differently, so the fiber curls into waves.

8. **Hard** A sweater weighs 450 g at 13% regain indoors. Outdoors in fog it reaches 27% regain. How many grams of water did it absorb?

Show answer

Dry mass $450/1.13 \approx 398 \text{ g}$; indoors $398 \times 1.13 \approx 450 \text{ g}$; outdoors $398 \times 1.27 \approx 506 \text{ g}$; absorbed about 56 g.

9. **Hard** Why does wool shed rain drops on its surface yet absorb water vapor inside?

Show answer

The waxy outer skin of the cuticle repels liquid water, but small vapor molecules diffuse through it into the water-loving keratin of the cortex.

10. **Hard** A raw fleece of 5.5 kg yields 3.3 kg of clean wool. What percent of the raw weight was grease, suint and dirt?

Show answer

$$2.2/5.5 \times 100\% = 40\% \quad 2.2/5.5 \times 100\% = 40\%$$

11. **Challenge** Gideon's second sign was a dry fleece on wet ground. Using what you know of wool, explain why that sign was the harder one to explain naturally.

Show answer

Wool readily absorbs water vapor and gathers dew, so a wet fleece on dry ground might be argued away. A fleece that stayed dry while dew soaked everything around it works against wool's nature, which is why Gideon asked for it.

COMMON MISTAKES

- Saying wool “repels water.” Its surface sheds drops, but its interior absorbs more vapor than any common fiber.
- Weighing a dried sample slowly. It regains moisture from the room while it sits on the scale.
- Thinking lanolin is the cause of wool allergies in every case. Some people react to lanolin; others simply feel the prickle of coarse fibers, which Lesson 2.2 explains.

Make it a game · Damp or Dry. Leave six small swatches (wool, cotton, linen, silk, polyester, acrylic) in a steamy bathroom for an hour. Each player, blindfolded, feels each one and ranks them from dampest to driest. Then weigh them against their dry masses recorded earlier. Score one point for every swatch ranked within one place of its measured regain.

Scripture. “And it was so: for he rose up early on the morrow, and thrust the fleece together, and wringed the dew out of the fleece, a bowl full of water.” (Judges 6:38, KJV)

God answered Gideon through a fleece, the very material that drinks water from the air. Studying wool closely helps us read this account with understanding, and its second sign, a dry fleece on wet ground, with wonder.

2.2 FROM SHEARING SHED TO MICRON COUNT

OBJECTIVES

- Describe shearing, skirting, classing and scouring, and how wool is graded by fiber diameter (micron), staple length and yield.
- Explain why fine wool feels soft and coarse wool prickles, and tell the story of merino sheep in Australia.
- Calculate clean yield, clean price, comfort factor and micron conversions from real data.

Warm-up. Gather three wool items: a fine merino sweater or base layer, an ordinary wool sweater or blanket, and a rug, a coarse sock or felt. Rub each against the inside of your wrist and rank them by prickle. Guess what makes the difference.

WATCH

Wool Measure

AgriLife Today - Texas Agriculture News · 10:09

<https://www.youtube.com/watch?v=Svzs8SD-T6U>

WHEN TO WATCH

After “How they figured it out.” Watch Texas A&M AgriLife scientists measure greasy wool for average fiber diameter, and note the numbers the instruments report.

BACKUP VIDEO

How to shear a sheep - Top Tips from Australian Shearing Trainer

RIST - Rural Industries Skill Training · 4:14

<https://www.youtube.com/watch?v=yWgKo5tNWjA>

Watch how the shearer holds the sheep and how the fleece comes off in one piece.

KEY TERMS

micron (μm)

One millionth of a meter, or one thousandth of a millimeter: the unit for wool fiber diameter. Fine merino is about 17–21 μm; a human hair is several times thicker.

classing

Sorting fleeces into lines of similar diameter, length, strength and color so buyers get even lots.

comfort factor

The percent of fibers in a sample that are 30 μm or finer. Fibers coarser than about 30 μm press into the skin and cause prickle.

skirting

Removing the dirty, short or matted edges of a fleece right after shearing.

clean yield

The mass of clean wool from scouring, as a percent of the greasy (raw) mass.

merino

A breed of sheep, first developed in Spain, prized for very fine, dense, crimped wool.

CORE IDEAS

The story. For centuries Spain guarded its merino flocks, whose fleece was the finest in Europe, and forbade their export. By the late 1700s the monopoly cracked, and merinos went to Saxony, France and beyond. In 1797 a few merinos from the Dutch colony at the southern tip of Africa reached New South Wales, and the officer John Macarthur and his wife Elizabeth set out to breed them. While John spent long years in England, Elizabeth ran the farm and the flock herself, selecting rams and ewes for finer, heavier fleeces. From such beginnings Australia became the world's great producer of fine merino wool.

How they figured it out. Buyers once judged wool by eye and hand: a classer pulls a lock, holds it to the light, counts the crimps, snaps it to test strength. Over the 1900s instruments replaced guesswork. Today a sample from each lot is measured by machine, laser or image analysis, for average fiber diameter in microns, the spread of diameters, staple length and strength, clean yield and color. A difference of one or two microns changes the price a farmer is paid, because fineness decides what a wool can become: next-to-skin underlayers, suits, sweaters, blankets or carpets.

The fabric science. Fineness is the most important property of wool. Finer fibers bend more easily, so they feel soft and drape well, and more of them fit in a yarn, so they spin finer, smoother yarn. Coarse fibers are stiff: when the end of a fiber thicker than about 30 μm presses on skin, it does not buckle but pokes, and nerve endings report it as prickle. That is why the comfort factor, the share of fibers 30 μm or finer, matters for anything worn next to the skin. Crimp tracks fineness too: fine merino may have many crimps per inch, coarse breeds only a few broad waves. Staple length matters for the spinning system: long wools go to worsted spinning (smooth, combed yarns), short ones to woolen spinning (lofty, carded yarns).

From shed to bale. Sheep are usually shorn once a year, in spring, by shearers who can strip a fleece in one piece in a few minutes. On the skirting table the fleece is thrown out flat, the stained and short edges are pulled away, and the classer assigns it to a line. Fleeces are pressed into bales, sampled, and sold on a *clean* basis: because grease and dirt may be a third to half of the raw weight, buyers pay for the clean wool they will actually get. At the mill the wool is scoured, carded, and for worsted yarns combed into a smooth rope of parallel fibers called top.

The studio lab. You will play wool classer and scourer. With one or two greasy locks, you will measure staple length, count crimps per inch, judge prickle against your wrist, then wash the wool in hot water and detergent and calculate its clean yield. If you can get two breeds, you will compare them.

PICTURE STUDY



The Sheepshearers, Jean-François Millet, c. 1857–61 · Oil on canvas · Art Institute of Chicago

Image: [Wikimedia Commons](#), public domain

Jean-François Millet grew up on a farm in Normandy and spent his life painting the work of French peasants with respect. Here a farm couple shears a sheep by hand with blade shears, long before electric handpieces.

Look closely

- Find the fleece already peeled back. Does it come off in one piece?
- Look at the tool. How do blade shears differ from scissors, and how would they be held?
- How is the sheep held still? Who holds and who cuts?
- Look at the color of the fleece's outer tips and of the wool closer to the skin. Why would they differ?

Talk about it

1. A skilled hand shearer could shear dozens of sheep a day; a modern shearer with a powered handpiece, a few hundred. What would that difference mean for a large flock?
2. Why would a shearer want the fleece to come off in one piece?
3. What would a wool classer need to do with this fleece next?

Safety first. Scour wool in a plastic tub or sink with hot tap water, not boiling water on the stove, and wear rubber gloves if the water is uncomfortably hot. Raw fleece can carry dirt and burrs: wash your hands after handling it. Keep pins and needles counted in the pincushion.

STUDIO LAB

The Wool Classer's Table: Staple, Crimp, Prickle and Yield

Question: How do two wools differ in staple length, crimp, prickle and clean yield? You will grade raw locks like a classer, then scour them and calculate yield.

You will need

- Two or three greasy (unwashed) locks from one or two breeds, about 5–15 g each (if only one breed is available, use one)
- Washed wool roving for comparison, if you have it
- A ruler in mm, the 10× magnifier, the 0.1 g scale and black paper
- A plastic tub, hot tap water, a liquid dish detergent, a colander and a towel
- Labeled zip-top bags

Steps

1. **Hypothesis.** Predict which lock is finer and which will have the higher clean yield.
2. Weigh each greasy lock to 0.1 g and record its breed if known.
3. Measure staple length: lay the lock unstretched on black paper and measure from base to tip in mm. Then gently stretch it straight and measure again.
4. Count crimps per inch along a 1-inch stretch of the lock (use the ruler under the magnifier). Record.
5. Prickle test: rub the lock tips against the inside of your wrist and rate 1 (soft) to 5 (prickly). Ask a family member to rate it too, without knowing which is which.
6. Snap test: hold a small tuft at both ends and pull sharply. Does it hold, or break in the middle (a tender spot from illness or poor feed)?
7. **Scour.** Fill the tub with hot tap water and a good squeeze of detergent. Lay the locks in a mesh bag or colander, push them under, and leave them 20 minutes without swishing. Lift, drain, repeat with fresh soapy water, then rinse twice in water of the same temperature.
8. Press the water out in a towel (do not wring) and dry the locks flat for a day. Weigh each. Calculate clean yield.
9. **Conclude.** Did fineness (crimps per inch and prickle rating) agree between locks? Which had the higher yield?
10. **Repeat round.** Look at the scoured wool under the magnifier and recount crimps. Did washing change the count or the staple length?

Tips

- Never swish or squeeze hot, soapy wool: heat, moisture and agitation together will start to felt it, which is the next lesson.
- Keep the rinse water the same temperature as the wash; sudden cold shocks wool and helps it felt.
- Fine wools usually have more crimps per inch and a lower clean yield, because they carry more grease.

Check your work

- ☐ I measured staple, crimp, prickle and strength before scouring and recorded every value with units.
- ☐ I scoured without felting and calculated clean yield.
- ☐ I used blind ratings for prickle and compared two samples or two raters.

LAB NOTEBOOK

1. Tape a greasy lock and a scoured lock side by side and label staple length, crimps per inch and yield.
2. Draw a fleece laid out on a skirting table and shade the parts a skirter would pull off.
3. Make a micron ladder from 15 to 40 μm and place merino, an ordinary sweater wool, a carpet wool and a human hair on it.

KEY FORMULAS

$$\text{clean yield} = \frac{m_{\text{clean}}}{m_{\text{greasy}}} \times 100\%$$

$$\text{clean yield} = m_{\text{greasy}} \times \text{clean yield} \times 100\%$$

$$\text{clean price} = \frac{\text{greasy price}}{\text{yield as a decimal}}$$

$$\text{clean price} = \text{yield as a decimal} \times \text{greasy price}$$

$$1 \mu\text{m} = 0.001 \text{ mm}, \quad 1 \text{ in} = 25,400 \mu\text{m}$$

$$1 \mu\text{m} = 0.001 \text{ mm}, \quad 1 \text{ in} = 25,400 \mu\text{m}$$

From history. Shearing has long been a contest of skill. In shearing sheds, a top shearer, or “gun,” earned a reputation by his daily tally, and in 1892 Jackie Howe of Queensland sheared 321 sheep in under eight hours with hand blades, a record for blade shearing that stood for many years. The sleeveless woolen work shirt Australian shearers wear is still called a “Jackie Howe.”

WORKED EXAMPLES

Example 1. A 12.0 g greasy lock weighs 7.2 g after scouring and drying to room conditions. Find the clean yield. At that yield, how much clean wool does a 5.0 kg fleece give?

Show solution

- Yield: $\frac{7.2 \text{ g}}{12.0 \text{ g}} \times 100\% = 60\%$ $7.2 \text{ g} \times 100\% = 60\%$.
- Fleece: $5.0 \text{ kg} \times 0.60 = 3.0 \text{ kg}$ $5.0 \text{ kg} \times 0.60 = 3.0 \text{ kg}$.

Answer: 60% yield; 3.0 kg of clean wool.

Example 2. Greasy wool sells for \$4.20 per kg at a 55% yield, and another lot for \$4.80 per kg at a 64% yield. Which is the better buy on a clean basis?

Show solution

- Lot A clean price: $\frac{\$4.20}{0.55} = \$7.64 \text{ per kg clean}$ $0.55 \$4.20 = \$7.64 \text{ per kg clean}$.
- Lot B clean price: $\frac{\$4.80}{0.64} = \$7.50 \text{ per kg clean}$ $0.64 \$4.80 = \$7.50 \text{ per kg clean}$.

Answer: Lot B: though it costs more per greasy kilogram, its clean wool is cheaper, \$7.50 against \$7.64.

Example 3. A test of 400 fibers finds 372 at 30 μm or finer. Find the comfort factor. Convert 19 μm to inches.

Show solution

- Comfort factor: $\frac{372}{400} \times 100\% = 93\%$ $400 \times 372 \times 100\% = 93\%$.
- Inches: $\frac{19 \mu\text{m}}{25,400 \mu\text{m/in}} = 0.00075 \text{ in}$ $25,400 \mu\text{m/in} \times 19 \mu\text{m} = 0.00075 \text{ in}$.

Answer: 93% comfort factor (a little low for next-to-skin wear, where buyers want 95% or more); 19 μm is about 0.00075 in, three-quarters of a thousandth of an inch.

PRACTICE

- Easy How many micrometers are in a millimeter?

Show answer

1,000.

- Easy Above about what diameter do wool fibers cause prickle?

Show answer

About 30 μm .

3. **Easy** In what year did merinos reach New South Wales, and who ran the Macarthur flock during John's absences?

Show answer

1797; Elizabeth Macarthur.

4. **Medium** A 9.5 g greasy lock scours to 5.0 g. Find the clean yield.

Show answer

$$5.0/9.5 \times 100\% \approx 52.6\%$$

5. **Medium** Greasy wool at \$5.00 per kg and 62% yield costs how much per clean kg?

Show answer

$$5.00/0.62 \approx \$8.06$$

6. **Medium** Of 250 fibers measured, 240 are 30 μm or finer. Comfort factor?

Show answer

$$240/250 = 96\%$$

7. **Medium** Why do buyers pay for wool on a clean basis rather than by greasy weight?

Show answer

Grease, suint and dirt can be a third to half of the greasy weight and vary from lot to lot; only the clean fiber becomes yarn.

8. **Hard** A flock of 120 ewes averages 4.5 kg greasy fleece at 58% yield. Clean wool sells at \$9.00 per kg. Find the clean kilograms and the value of the clip.

Show answer

$$\text{Greasy } 540 \text{ kg}; \text{ clean } 540 \times 0.58 = 313.2 \text{ kg}; \text{ value } 313.2 \times 9 = \$2,818.80$$

9. **Hard** A human hair is about 70 μm across. How many 18 μm merino fibers laid side by side span the same width?

Show answer

$$70/18 \approx 3.9$$

10. **Hard** Explain why fine wool is usually worsted-spun into suiting while short, coarse wool is often woolen-spun into blankets or carpets.

Show answer

Long, fine, even fibers can be combed parallel and twisted into smooth, strong, fine worsted yarn; short, variable fibers are carded into a lofty, airy woolen yarn whose bulk suits blankets and whose toughness suits carpets.

11. **Challenge** A farmer can choose rams that lower her flock's average diameter by 1.5 μm , raising the clean price from \$8.50 to \$10.20 per kg, but fleece weight falls from 5.0 to 4.6 kg greasy at the same 60% yield. Per ewe, is the change worth it?

Show answer

$$\text{Before: } 5.0 \times 0.6 \times 8.50 = \$25.50 \quad \text{After: } 4.6 \times 0.6 \times 10.20 = \$28.15$$

COMMON MISTAKES

- Measuring a lock stretched and calling it the staple. Record both, but the classer's staple is the natural, unstretched length.
- Comparing yields of locks scoured differently. Same water, detergent, time and drying for every sample.
- Assuming all wool itches. Prickle comes from coarse fibers; fine merino is worn next to the skin by many people who cannot wear ordinary wool.

Make it a game · Prickle Ladder. Collect six wool items from fine to coarse. A parent hides the labels and numbers them. Each player, eyes closed, rubs each on the inside of the wrist and arranges them from softest to most prickly. Reveal the labels (and micron counts where tags give them). One point for each item in its correct place; the winner names the micron number where prickle starts.

2.3 FELTING AND SHRINKAGE: WOOL'S SCALES AT WORK

OBJECTIVES

- Explain how scales, heat, moisture, soap and agitation make wool felt, and how fulling and superwash treatments use or stop it.
- Distinguish relaxation shrinkage from felting shrinkage and calculate shrinkage in length, width and area.
- Run a controlled felting lab and plan a knitted or woven piece that will be felted to a target size.

Warm-up. Ask the family whether anyone has ever shrunk a wool sweater in the wash. What happened, and what was the water temperature? Write down the story, then predict what you would need to do to shrink a sweater on purpose.

WATCH

Watch An Artisan Painstakingly Create Specialty Nuno Felt From Marino Wool

Science Channel · 3:00

<https://www.youtube.com/watch?v=Q9EHNDPDRdU>

WHEN TO WATCH

After “The fabric science.” Watch for the three things the felt-maker adds to the wool, and notice how long the rolling takes.

BACKUP VIDEO

What Happens to My Wool Sweater in the Washer?

SciShow · 2:27

<https://www.youtube.com/watch?v=sSQLufD618>

A short explanation of why a sweater shrinks in the washer, for review before the lab.

KEY TERMS

felting

The permanent matting and shrinking of wool fibers into a dense cloth, caused by moisture, heat, alkali or soap, and agitation.

fulling

Deliberately felting woven wool cloth to make it thicker, denser and warmer; also called walking or waulking.

superwash

A treatment, usually chlorine followed by a thin polymer coating, that smooths or masks wool's scales so the fabric can be machine-washed without felting.

directional friction effect

Wool fibers slide more easily toward their root than toward their tip because of the scales, so agitation walks them in one direction and locks them together.

relaxation shrinkage

Shrinkage from the release of tension put into yarns and fabric during manufacture; it happens in the first wash or two and then stops.

area shrinkage

The percent loss of a fabric's area: $1 \text{ minus } (\text{new length} \times \text{new width}) \div (\text{old length} \times \text{old width}), \text{ times } 100\%$.

CORE IDEAS

The story. Felt is probably the oldest fabric of all, made by tramping and rolling wet wool long before anyone wove. The nomads of the Asian steppes still build their round tents of thick felt. Weavers later learned to felt their cloth on purpose. In medieval Europe, woven wool was fullled: soaked, soaped and pounded, first by people treading it in tubs and later by water-powered wooden hammers in fulling mills. The fuller's trade was so familiar that Jesus could say, “No man also seweth a piece of new cloth on an old garment: else the new piece that filled it up taketh away from the old, and the rent is made worse.” An unshrunk patch, once washed, shrinks and tears its mended neighbor.

How they figured it out. Fullers knew that hot water, soap or stale urine, and pounding made cloth thicken and shrink, but not why. The microscope showed the scales, and in the 1900s textile scientists measured that a wool fiber slides more easily root-first than tip-

first. When wet, warm, soapy wool is pushed and released over and over, each fiber ratchets along in one direction, burrowing and tangling among its neighbors. Because the scales catch, the fibers cannot back out: felting is permanent.

The fabric science. Felting needs four things together: *moisture* to soften and swell the fibers, *heat* to speed it, *alkali or soap* to lift and lubricate the scales, and *agitation* to drive the ratchet. Remove any one and felting nearly stops: wool hand-washed in cool water without rubbing does not felt. Felted shrinkage can be dramatic, a quarter to a half of the length in each direction, which may cut the area by half or more. It is different from *relaxation shrinkage*, the small, one-time shrinkage of any fabric (wool, cotton or linen) as yarns pulled tight on the loom relax in their first washing; good fabric is often pre-shrunk at the mill for exactly this reason.

Stopping it. Superwash wool is treated so its scales no longer catch: a chlorine treatment softens and partly removes them, and a very thin polymer coating smooths the surface. Superwash yarns can go in a machine wash, but they will never felt, so they cannot be used where felting is wanted. Careful hand washing protects ordinary wool: lukewarm water, a mild wool wash, a gentle soak with no rubbing, rinse at the same temperature, roll in a towel and dry flat.

The studio lab. You will mark exact squares on wool swatches and treat them four ways: a cool, gentle soak; a hot soak without agitation; hot, soapy shaking in a jar; and a superwash swatch shaken the same way. Measuring length, width and area before and after will show which of the four conditions matters most. Then you will felt a knitted or woven swatch to a target size, the way felt makers plan bags and slippers.

PICTURE STUDY



The Hatter (Le chapelier), Jean Frédéric Wentzel (publisher), Wissembourg, 19th century · Hand-colored print · Image from Wikimedia Commons (public domain)

Image: [Wikimedia Commons](#), public domain

Hats were the great felt product of Europe for centuries. Hatters bowed loose fiber into an even layer, then rolled and worked it in hot water to felt it into a cone, which they stretched and shaped on a wooden block. The Wentzel firm of Wissembourg, in Alsace, printed popular colored pictures of trades like this one.

Look closely

- Find the hatter's tools. Which might be used to shape a felt cone, and which to finish it?
- Look for any steam, kettle or water. Where in the process would heat and moisture come in?
- Find finished hats. How stiff do they look, and what made them hold their shape?
- What is the hatter wearing to protect himself or his clothes?

Talk about it

1. Felt hats needed fine, short fibers that felted quickly. Which animal fibers from this unit would felt best, and which would not felt at all?
2. A hatter worked with hot water and agitation all day. Which of the four felting conditions did he control most carefully?
3. Why might a felt hat shed rain better than a woven one?

Safety first. Use hot tap water, not boiling water from the stove, for the felting jar, and wear rubber gloves if it is uncomfortably hot. Screw the jar lid on tightly and shake over a sink. A washing machine felting run is done with a parent's permission, in a mesh bag, and the lint trap is checked afterward.

STUDIO LAB

The Felting Lab: Which Condition Matters Most?

Question: Which condition, heat, soap or agitation, does most to felt wool, and does superwash wool resist? You will treat marked swatches four ways and measure shrinkage. Then you will felt a swatch to a target size.

You will need

- A 100% wool sweater from a thrift store (label must not say superwash or machine washable), and a superwash wool sock or yarn swatch
- A permanent fabric marker or contrasting basting thread, a ruler and scissors
- Three clean quart jars with lids, a bowl, hot tap water, cool water and dish soap
- A timer and a towel

MARKED FELTING SWATCHES

Finished size: Five swatches, each 5 × 5 in (12.5 × 12.5 cm), with a 10 × 10 cm marked square · About 20 minutes

Fabric and notions

- Four 5 × 5 in squares cut from the wool sweater body, all with the knit columns running the same way
- One 5 × 5 in superwash swatch (knit one, or cut from a superwash sock)
- Contrasting cotton thread for basting the 10 cm squares

How to make it

1. Cut four squares from the sweater body, avoiding ribbing and seams, with the knit columns (wales) running up and down on every one.
2. With a ruler, baste a 10 × 10 cm square in the middle of each swatch using long running stitches in contrasting cotton thread. Mark which direction is length.
3. Measure each marked square to the nearest millimeter in both directions and record it, even if it is not exactly 10.0.
4. Label each swatch with a safety pin or a tag: A cool soak, B hot soak, C hot soap shake, D superwash hot soap shake, E spare.
5. Cut the superwash swatch and baste and measure it the same way.

Fabric check: The sweater must be 100% wool or another animal fiber and must not be labeled superwash, machine washable or shrink-resistant. Acrylic and cotton will not felt, which makes either a good extra control. Wool-sensitive students can do the lab in rubber gloves.

Steps

1. **Hypothesis.** Rank swatches A–D by how much they will shrink, and predict the area shrinkage of the worst one.
2. **A, cool soak.** Soak in cool water with no soap for 10 minutes without moving it. Press dry in a towel.
3. **B, hot soak.** Soak in hot tap water with no soap for 10 minutes without moving it. Press dry.
4. **C, hot soap shake.** Put the swatch in a jar of hot tap water with a squirt of dish soap and shake hard for 10 minutes (take turns). Rinse in cool water. Press dry.
5. **D, superwash.** Treat the superwash swatch exactly like C.
6. Dry all swatches flat for a day. Measure each marked square and calculate length, width and area shrinkage. Make a bar graph of area shrinkage.
7. **Target-size round.** Using swatch C's shrinkage, calculate the size to cut swatch E so it felts to exactly 3 × 3 in. Cut, shake it like C, dry, and measure. How close did you come?
8. **Conclude.** Which single condition changed the result most? Did superwash resist? Did your target piece hit its size?

9. **Make something.** Use the felted fabric for a coaster, a needle book or a pair of mitten cuffs: felted wool will not fray, so the edges need no finishing.

Tips

- Shake hard and steadily; agitation is the engine of felting. Ten minutes of shaking is a real workout.
- Felting is not always even: knits often shrink more in length than width. Record both directions.
- A washing machine on hot with a pair of old jeans for friction felts a whole sweater in one or two cycles. Check it every few minutes; you cannot undo it.

Check your work

- ☐ I treated the swatches so only one condition changed between pairs.
- ☐ I measured before and after to the millimeter and calculated length, width and area shrinkage.
- ☐ I planned and checked a target size using my own shrinkage data.

LAB NOTEBOOK

1. Draw two wool fibers side by side with their scales, and arrows showing which way each can slide. Under it, explain in three sentences why felting cannot be undone.
2. Tape in the four lab swatches in a row with their area shrinkage written beneath each.
3. Copy Mark 2:21 and write one mending rule it teaches.

KEY FORMULAS

$$\text{length shrinkage} = \frac{L_0 - L}{L_0} \times 100\%$$

$$\text{length shrinkage} = \frac{L_0 - L}{L_0} \times 100\%$$

$$\text{area shrinkage} = \left(1 - \frac{L \times W}{L_0 \times W_0}\right) \times 100\%$$

$$\text{area shrinkage} = (1 - \frac{L \times W}{L_0 \times W_0}) \times 100\%$$

$$\text{size before felting} = \frac{\text{target size}}{1 - \text{shrinkage as a decimal}}$$

$$\text{size before felting} = \frac{\text{target size}}{1 - \text{shrinkage as a decimal}}$$

From history. In the Scottish Highlands and Hebrides, women fulled newly woven tweed by hand around a long table, passing the wet cloth from hand to hand and beating it on the boards in rhythm with waulking songs. The songs set the pace of the work and kept count of the time the cloth needed, and some are still sung today.

WORKED EXAMPLES

Example 1. A 10.0×10.0 cm square marked on a wool sweater measures 7.6 cm long and 8.4 cm wide after a hot, soapy wash. Find the length, width and area shrinkage.

Show solution

$$1. \text{ Length: } \frac{10.0 - 7.6}{10.0} \times 100\% = 24\%$$

$$2. \text{ Width: } \frac{10.0 - 8.4}{10.0} \times 100\% = 16\%$$

$$3. \text{ Area: } \left(1 - \frac{7.6 \times 8.4}{10.0 \times 10.0}\right) \times 100\% = (1 - 0.638) \times 100\% = 36.2\%$$

Answer: 24% in length, 16% in width, 36% in area. Notice that area shrinkage is not the sum of the two; it compounds.

Example 2. A felted bag should finish 9 in wide and 11 in tall. Your swatch test shrank 22% in width and 30% in height. What size must you knit it before felting?

Show solution

1. Width before: $\frac{9 \text{ in}}{1 - 0.22} = \frac{9}{0.78} = 11.5 \text{ in} - 0.229 \text{ in} = 0.789 = 11.5 \text{ in}.$
2. Height before: $\frac{11 \text{ in}}{1 - 0.30} = \frac{11}{0.70} = 15.7 \text{ in} - 0.3011 \text{ in} = 0.7011 = 15.7 \text{ in}.$

Answer: Knit about 11½ in wide and 15¾ in tall.

Example 3. Mark 2:21 in numbers. A patch of unshrunk wool 4 in square is sewn over a hole in an old, fully shrunk coat. In its first wash the patch shrinks 8% each way. How much smaller is each side, and what happens to the stitches?

Show solution

1. New side: $4 \text{ in} \times (1 - 0.08) = 3.68 \text{ in}$ $4 \text{ in} \times (1 - 0.08) = 3.68 \text{ in}.$
2. Loss per side: $4 - 3.68 = 0.32 \text{ in}$ $4 - 3.68 = 0.32 \text{ in},$ about ¾ in.
3. The old coat does not shrink, so the patch pulls its stitches and the weakened cloth around them by about a third of an inch on every side.

Answer: Each side shortens about 0.32 in; the patch drags at the old cloth and “the rent is made worse.” Pre-shrink every patch.

PRACTICE

1. **Easy** Name the four conditions that together cause felting.

Show answer

Moisture, heat, soap or alkali, and agitation.

2. **Easy** What is fulling?

Show answer

Felting woven wool on purpose to thicken and densify it.

3. **Easy** Which way does a wool fiber slide more easily: toward its root or its tip?

Show answer

Toward its root (root-first).

4. **Medium** A 20 cm length shrinks to 15 cm. Find the shrinkage.

Show answer

$$5/20 \times 100\% = 25\% \quad 5/20 \times 100\% = 25\%$$

5. **Medium** A 10 × 10 cm square becomes 8 × 9 cm. Find the area shrinkage.

Show answer

$$(1 - 72/100) \times 100\% = 28\% \quad (1 - 72/100) \times 100\% = 28\%$$

6. **Medium** Why does a superwash yarn not work for a felted slipper pattern?

Show answer

Its scales are smoothed or coated so they cannot catch; it will not felt.

7. **Medium** Explain the difference between relaxation shrinkage and felting shrinkage.

Show answer

Relaxation shrinkage is small and one-time, as manufacturing tension relaxes in any fiber; felting shrinkage is large, progressive and permanent, and only in scaled animal fibers.

8. **Hard** A felted pot holder must finish 8×8 in. The swatch shrank 25% in length and 18% in width. What knitted size do you need?

Show answer

$8/0.75 \approx 10.7$ in $8/0.75 \approx 10.7$ in long and $8/0.82 \approx 9.8$ in $8/0.82 \approx 9.8$ in wide.

9. **Hard** A sweater's body is 24 in long and 20 in wide (front). After an accidental hot wash it is 17 in long and 16 in wide. Find the area shrinkage.

Show answer

$$(1 - 272/480) \times 100\% \approx 43\% (1 - 272/480) \times 100\% \approx 43\%$$

10. **Hard** Write care directions for an ordinary (not superwash) wool sweater, giving the reason for each step.

Show answer

Lukewarm water (less heat), mild wool wash (no strong alkali), soak without rubbing (no agitation), rinse at the same temperature (no shock), press water out in a towel and dry flat (no stretching or tumbling).

11. **Challenge** Explain Mark 2:21 to someone who has never sewn, using the words fulling and shrinkage, and apply it to a modern mending job.

Show answer

New wool cloth that has not been fulling will shrink the first time it is washed; sewn onto an old, already-shrunk garment, it pulls at the weak cloth and tears it worse. Today: prewash a cotton patch before sewing it onto old jeans so it does not shrink and pucker.

COMMON MISTAKES

- Adding up length and width shrinkage to get area shrinkage. Multiply the new dimensions; area shrinkage compounds.
- Testing a sweater labeled “wool blend.” Synthetic content slows or stops felting; read the label.
- Hot washing, then rinsing in cold water. The shock and agitation finish what the wash began.

Make it a game · Shrink Prediction Showdown. Before swatch C comes out of the jar, every family member writes a prediction of its area shrinkage. Closest guess wins and chooses what the felted fabric will become. Bonus round: guess how many minutes of shaking it would take to shrink a swatch by half its area, then test it.

Scripture. “No man also seweth a piece of new cloth on an old garment: else the new piece that filled it up taketh away from the old, and the rent is made worse.” (Mark 2:21, KJV)

Jesus drew his lesson from the fuller's trade: unshrunk cloth shrinks when washed and tears the old garment it was meant to mend. Every pre-shrunk patch in this course is a small obedience to that good sense.

2.4 MOHAIR, CASHMERE, ALPACA AND CAMEL

OBJECTIVES

- Describe where mohair, cashmere, alpaca and camel hair come from, how each is harvested, and what makes each distinct from sheep's wool.
- Explain how fiber diameter, scale shape, a hollow medulla and the absence of grease change luster, softness, weight and warmth.
- Measure insulation with a cooling-rate test and compare cost per gram fairly.

Warm-up. Look through the house for any label that says mohair, cashmere, alpaca, camel, angora or “specialty fiber.” If you find none, look up the price of a plain wool sweater and a cashmere one. Write down your guess of why the difference is so large.

WATCH

From Fleece to Yarn ~ Tour of a Fiber Mill

[Butterfield Alpaca Ranch](#) · 22:20

https://www.youtube.com/watch?v=pIC_7rfMg3s

WHEN TO WATCH

After “How they figured it out.” Follow alpaca fleece through a small mill (washing, picking, dehairing, carding, drafting, spinning, plying) and name what each machine does. Watch at least the first ten minutes.

BACKUP VIDEO

Combing a Cashmere Goat (part 1)

[Cashmere Goat Association \(CGA\)](#) · 1:47

<https://www.youtube.com/watch?v=zE752QEmsFI>

Watch how the comb gathers only the loosened undercoat of a cashmere goat, and compare it with shearing in Lesson 2.2.

KEY TERMS

specialty hair fibers

Animal fibers other than sheep's wool: mohair, cashmere, alpaca, camel, angora rabbit and others. U.S. labels may name them specifically.

cashmere

The very fine soft undercoat (down) of cashmere goats, separated from the coarse outer guard hair by combing and dehairing.

dehairing

Machine separation of fine down from coarse guard hairs, essential for cashmere and camel hair.

mohair

The long, lustrous fiber of the Angora goat, with smooth, flat scales that give shine and resist felting.

alpaca

The fiber of the alpaca, a South American camelid; it has little grease and many fibers have a partly hollow core.

medulla

A hollow or air-filled core in some animal fibers; it makes the fiber lighter and adds insulation.

CORE IDEAS

The story. Each of these fibers comes from a hard country. The Angora goat takes its name from the old name of Ankara, in Turkey, where its silky mohair was woven for centuries; in the 1800s Angora goats came to South Africa and to the dry Edwards Plateau of Texas, which became one of the world's mohair centers. Cashmere takes its name from Kashmir, whose weavers made the famous shawls; the fiber itself grows as a winter undercoat on goats of the high, cold plateaus of Central Asia, today mostly in China and Mongolia. Alpacas were bred by the peoples of the Andes from wild vicuñas, and camel hair is gathered from Bactrian camels, which shed their undercoat in clumps each spring.

How they figured it out. Getting the fine fiber without the coarse took ingenuity. Angora goats are shorn twice a year, and their fleece is nearly all one kind of fiber. Cashmere goats grow two coats: long, coarse guard hair outside and a soft down beneath. Herders

comb the down out in spring as it loosens, or shear the whole coat, and then mills dehair it by machine, separating the down by its fineness. Each goat yields only a few ounces of usable cashmere a year, which explains much of its price. Alpacas are shorn once a year; their fleece is skirted and sorted by fineness and color, because alpacas come in more natural colors than any other fiber animal.

The fabric science. Small differences in structure make big differences in the cloth. *Mohair's* scales are thin and lie flat, so its surface reflects light like glass (luster) and it felts little; it is strong, springy and takes dye brilliantly. *Cashmere* is very fine (by U.S. law, fiber labeled cashmere must average 19 microns or less), with thin scales, so it is extremely soft and drapes beautifully, though it pills and wears faster than tougher wool. *Alpaca* has little lanolin, so it needs little scouring, and many of its fibers have a partly hollow medulla, making it light and warm for its weight; its scales are low, giving a smooth, silky hand. *Camel hair* down is soft and warm and is usually left its natural golden tan.

Fairly compared. None of these is simply better than wool. Sheep's wool is tougher, more resilient, far cheaper and comes in a much wider range of grades. Mohair is stronger and shinier but can feel scratchy in coarse grades. Cashmere is softest but least durable. Alpaca is warm and soft but drapes heavily and can stretch. The right fiber depends on the job: a hard-wearing sock, a light warm scarf, a coat that will last twenty years. Blends often take the best of each: a little cashmere for softness, wool for wear, nylon in a sock heel for strength.

The studio lab. Warmth comes mostly from still air trapped among fibers, so you will measure it. You will wrap identical jars of hot water in equal masses of different fibers or yarns and record how fast each cools. The slowest-cooling jar has the best insulation per gram, and you can then compare it with the price per gram.

PICTURE STUDY



Shawl of Joined Fragments (Kashmir shawl), Unknown weavers of Kashmir, 19th century · Goat-hair (pashmina) twill tapestry weave · The Metropolitan Museum of Art, New York

Image: [Wikimedia Commons](#), public domain

The shawls of Kashmir were woven from the fine undercoat of Himalayan goats, the fiber the West came to call cashmere. Their weavers built the curving cone-shaped patterns, later called paisley, thread by thread in a slow twill-tapestry technique, and a single fine shawl could take a workshop many months. Worn pieces were treasured, cut up and joined into new shawls, as this one was.

Look closely

- Look where the plain center meets the patterned borders. Could the parts have been woven separately and joined, as the title says?
- Look for the curved cone or teardrop motif. How many times does it repeat?
- Count the main colors. Each was a separate bobbin of dyed fiber for the weaver.
- Look at the edges and borders. Why would a weaver put the densest pattern there?

Talk about it

1. This fiber was so precious that worn shawls were cut up and rejoined. What does that tell you about the value of a few ounces of down per goat?
2. Why would a very fine, soft fiber be chosen for a shawl worn over the shoulders, rather than for a rug?
3. Mills in Paisley, Scotland, later copied these patterns in wool. What would be gained and lost?

Safety first. Hot water for the jars comes from the tap or a kettle poured by a parent; carry jars with a towel and set them on a heat-proof surface. Keep the thermometer probe in a stable position so it does not tip the jar. Count pins and needles at the end of the session.

STUDIO LAB

Warmth per Gram: The Cooling-Jar Test

Question: Which fiber gives the most insulation per gram? You will wrap identical jars of hot water in equal masses of four fibers and measure cooling rates, then compare warmth with cost.

You will need

- Five identical glass jars (pint or quart) with lids, one left unwrapped as a control
- 30 g each of four yarns or fibers: wool, one specialty fiber (alpaca, mohair blend or cashmere blend) if available, cotton, and acrylic or polyester
- A kitchen or candy thermometer (one per jar is ideal; one moved quickly between jars works)
- Rubber bands, a kettle, a timer and the scale

Steps

1. **Hypothesis.** Rank the four fibers and the bare jar by how slowly they will cool.
2. Weigh out exactly 30 g of each yarn. Wrap each around its own jar as evenly as you can, from the bottom to the shoulder, and hold the end with a rubber band. Leave one jar bare.
3. Have a parent fill all five jars with hot water from one kettle, to the same level. Close the lids with the thermometer through a small hole, or open each briefly to read it.
4. Record every jar's temperature at the start and every 5 minutes for 40 minutes. Keep all jars on the same surface, away from drafts and sun.
5. Calculate each jar's average cooling rate and graph temperature against time for all five.
6. Find each yarn's price per gram from its label and calculate cost per gram.
7. **Conclude.** Which fiber insulated best per gram? Was the best insulator also the best value?
8. **Repeat round.** Dampen the wool and cotton wraps with a spray bottle (same amount of water each) and run the test again. Which keeps its warmth when damp?

Tips

- Even wrapping matters more than fiber in a rough test. Wind snugly but not tight; crushing the yarn squeezes out the air that does the insulating.
- If you have only one thermometer, read the jars in the same order each time and note the minute of each reading.
- Compare your damp result with Lesson 2.1: wool's regain and heat of sorption help it here.

Check your work

- ☐ I used equal masses, identical jars and the same starting water for every test.
- ☐ I graphed five cooling curves and calculated cooling rates with units.
- ☐ I compared warmth with cost per gram and wrote a fair verdict.

LAB NOTEBOOK

1. Make a four-column fact table for mohair, cashmere, alpaca and camel hair: animal, homeland, harvest, diameter, best use, honest weakness.

2. Draw the scale pattern of wool (raised, overlapping) beside mohair (thin, flat), and explain the difference in luster and felting.
3. Paste your cooling graph and circle the curve of the best value for money.

KEY FORMULAS

$$\text{average cooling rate} = \frac{T_{\text{start}} - T_{\text{end}}}{\text{time}}$$

$$\text{average cooling rate} = \frac{T_{\text{start}} - T_{\text{end}}}{\text{time}}$$

$$\text{cost per gram} = \frac{\text{price}}{\text{mass in grams}}$$

$$\text{cost per gram} = \frac{\text{price}}{\text{mass in grams}}$$

From history. In the early 1800s Kashmir shawls were the height of fashion in Europe, and weavers in Paisley, Scotland, built a whole industry imitating them in wool and silk on Jacquard looms. The cone-shaped motif became so linked with the town that it is still called paisley around the world.

WORKED EXAMPLES

Example 1. Two jars start at 60.0 °C. After 40 minutes the jar wrapped in 30 g of alpaca yarn reads 48.4 °C and the jar wrapped in 30 g of cotton yarn reads 43.2 °C. Find each average cooling rate.

Show solution

1. Alpaca: $\frac{60.0 - 48.4}{40} = 0.29 \text{ °C/min}$
2. Cotton: $\frac{60.0 - 43.2}{40} = 0.42 \text{ °C/min}$

Answer: Alpaca 0.29 °C/min, cotton 0.42 °C/min: the alpaca-wrapped jar lost heat about 30% more slowly.

Example 2. A 50 g skein of cashmere costs \$28.00 and a 100 g skein of merino costs \$14.50. Find each cost per gram and the cost of the yarn for a 150 g scarf in each.

Show solution

1. Cashmere: $\frac{\$28.00}{50 \text{ g}} = \$0.56/\text{g}$; scarf $150 \times 0.56 = \$84.00$
2. Merino: $\frac{\$14.50}{100 \text{ g}} = \$0.145/\text{g}$; scarf $150 \times 0.145 = \$21.75$

Answer: Cashmere \$0.56 per gram (\$84 for the scarf); merino \$0.145 per gram (\$21.75), nearly four times cheaper.

Example 3. A cashmere goat yields 120 g of combed fiber, of which 45% is guard hair removed in dehairing. How many goats' clean down does a 300 g sweater need, allowing 15% loss in spinning and knitting?

Show solution

1. Clean down per goat: $120 \text{ g} \times (1 - 0.45) = 66 \text{ g}$
2. Down needed for the sweater: $\frac{300 \text{ g}}{1 - 0.15} = 353 \text{ g}$
3. Goats: $\frac{353 \text{ g}}{66 \text{ g/goat}} = 5.366$, so about 5 to 6 goats' yearly down.

Answer: The down of about five or six goats for one sweater.

PRACTICE

1. **Easy** Match each fiber to its animal: mohair, cashmere, alpaca, camel hair.

Show answer

Mohair: Angora goat. Cashmere: cashmere goat (undercoat). Alpaca: alpaca. Camel hair: Bactrian camel.

2. **Easy** What is the maximum average diameter for fiber labeled cashmere in the United States?

Show answer

19 microns.

3. **Easy** Why does mohair shine?

Show answer

Its thin, flat scales give a smooth surface that reflects light evenly.

4. **Medium** A jar cools from 58 °C to 46 °C in 30 minutes. Find the average cooling rate.

Show answer

$12/30 = 0.40\text{ }^{\circ}\text{C}/\text{min}$

5. **Medium** A 25 g ball of mohair blend costs \$9.75. Find the cost per gram and the cost of 175 g.

Show answer

\$0.39/g; \$68.25

6. **Medium** Why does alpaca need less scouring than sheep's wool?

Show answer

It has very little lanolin (grease).

7. **Medium** Give one honest strength and one honest weakness of cashmere compared with merino wool.

Show answer

Strength: softer, lighter and finer. Weakness: less durable, pills more, far more expensive.

8. **Hard** In a test, a jar in 30 g of wool cools at 0.33 °C/min and a jar in 30 g of polyester fiberfill at 0.31 °C/min. What does that suggest about the source of insulation?

Show answer

Insulation comes mostly from trapped still air, not the fiber type; any lofty, fine fiber that traps air insulates well.

9. **Hard** A goat gives 140 g of combed fiber with 40% guard hair. How much clean down is that, and how many goats for a 200 g scarf with 10% loss?

Show answer

Down 84 g; need $200/0.9 \approx 222\text{ g}$; $222/84 \approx 2.6$, about 3 goats.

10. **Hard** Why might a hollow medulla make a fiber warmer for its weight but weaker?

Show answer

Air in the core adds insulation and lowers mass, but there is less solid protein to bear load, so the fiber is weaker for its diameter.

11. **Challenge** Design the yarn for a hard-wearing, warm winter sock for a farmer. Choose fibers and percentages and justify each in one sentence.

Show answer

For example: 70% wool (warmth, moisture handling, resilience), 20% mohair (strength and wear in heel and toe), 10% nylon (abrasion resistance). Any well-reasoned blend earns credit.

COMMON MISTAKES

- Confusing angora (rabbit fiber) with mohair (Angora goat fiber). The animals share a place name, not a fiber.
- Judging warmth by a single fabric's thickness without equal mass. Compare per gram or per area at equal weight.
- Assuming a luxury fiber is better for every job. Cashmere is soft but makes a poor work sock.

Make it a game · Price Is Right: Fiber Edition. A parent prints or writes out the prices of ten yarns of different fibers without the fiber names. Players match each price to a fiber: acrylic, cotton, wool, superwash merino, alpaca, mohair, silk, cashmere, camel, linen. One point for each exact match, and a bonus for anyone who can explain the most expensive one using the word dehairing.

2.5 SILK: FIBROIN, THE SILKWORM AND THE SILK ROAD

OBJECTIVES

- Describe sericulture: the silkworm, the cocoon, reeling, and degumming, and the structure of fibroin and sericin.
- Tell the history of silk from ancient China to Justinian's monks, separating legend from record.
- Identify protein fibers by burn and bleach tests, explain how to care for them, and calculate degumming loss and filament size.

Warm-up. Find something silk (a tie, a scarf, an old blouse; check the label). Hold it to the light and slowly turn it. Describe the shimmer. Then squeeze it in your fist: does it wrinkle like linen or spring back like wool?

WATCH

Traditional Silk-Making - From AMNH's Silk Road Exhibition

[American Museum of Natural History](#) · 3:06

<https://www.youtube.com/watch?v=IFo3SxqH2-A>

WHEN TO WATCH

After “How they figured it out.” Watch the sericulturist soften cocoons and reel several filaments together into one thread; count the cocoons in the basin.

BACKUP VIDEO

How Silk Is Made

[How It's Made](#) · 4:14

<https://www.youtube.com/watch?v=HzpF4niyDeg>

A longer look at silk from the mulberry leaf and the cocoon to dyeing and the handloom.

KEY TERMS

sericulture

Raising silkworms (the domestic silkworm) on mulberry leaves to harvest their cocoons for silk.

sericin

A gummy protein that glues the two fibroin strands and the cocoon together; it makes up about a fifth to a quarter of raw silk's weight and is washed off in degumming.

degumming

Boiling raw silk gently in soapy water to remove sericin, leaving soft, shining fibroin.

fibroin

The protein of the silk filament itself; its chains fold into tightly packed sheets that make silk strong and lustrous.

reeling

Unwinding the continuous filaments of several softened cocoons together into one raw silk thread.

filament

A fiber of practically unlimited length. Silk is the only natural filament; one cocoon can give hundreds of meters to about a kilometer of reelable thread.

CORE IDEAS

The story. Chinese tradition credits the discovery of silk to Leizu, the wife of the legendary Yellow Emperor, who, the story says, saw a cocoon fall into her hot tea and unwind into a shining thread. That is a legend, told as one; what archaeology shows is that silk was being made in China thousands of years ago, and that for centuries China kept the secret. Silk traveled west along the trade routes later named the Silk Road, and Rome paid dearly for it. Around AD 552, according to the historian Procopius, monks came to the emperor Justinian in Constantinople and offered to bring silkworm eggs from the East. They returned with eggs hidden in hollow canes, and the Byzantine silk industry was born.

How they figured it out. Sericulture is a careful partnership with an insect. The silkworm, a caterpillar, eats mulberry leaves for about a month, growing many thousands of times heavier, then spins its cocoon over two or three days, swinging its head in figure eights and laying down a single continuous strand. To reel it, workers soften cocoons in hot water, find the ends, and draw several

filaments together onto a reel, the natural gum sticking them into one thread. The cocoons are heated before reeling so the moth does not break the filament by emerging; the pupa dies, a hard fact of how reeled silk has always been made. Wild silks, such as tussah, come from cocoons the moth has left, so they are spun from shorter fibers.

The fabric science. The silkworm squeezes two strands of liquid protein, *fibroin*, through spinnerets in its head, coated in a gum, *sericin*. As the protein is drawn out, its chains, built largely from the small amino acids glycine and alanine in a repeating pattern, line up and fold into flat, tightly stacked sheets with hydrogen bonds between them. That ordered, crystalline structure makes silk one of the strongest natural fibers for its fineness. Each strand has a rounded triangular cross-section that works like a prism, scattering light into the soft shimmer silk is famous for. Degumming in hot soapy water removes the sericin, losing a fifth to a quarter of the weight and revealing the soft, lustrous fibroin.

Caring for protein fibers. Silk and wool share protein's weaknesses. Chlorine bleach dissolves them, so it is never used on either. Strong alkali (washing soda, harsh detergents) damages them, and high heat scorches them. Sunlight weakens and yellows silk over time, which is why museum silks are kept in low light. Perspiration and deodorants can rot silk underarms. Moths and carpet beetles eat keratin, especially when it is soiled. Gentle washing in lukewarm water with a mild, neutral detergent, drying out of the sun, a cool iron and clean storage keep protein fibers for generations.

The studio lab. With a parent beside you, you will burn-test silk and wool alongside a polyester satin that looks like silk, and your parent will run a chlorine bleach test showing protein fibers dissolve while cellulose and polyester do not. These results complete your protein pages of the identification kit and show you, safely, why care labels say what they say.

PICTURE STUDY



Court Ladies Preparing Newly Woven Silk, Attributed to Emperor Huizong, after a lost painting by Zhang Xuan, Early 12th century (original 8th century) · Ink and color on silk (handscroll) · Museum of Fine Arts, Boston

Image: [Wikimedia Commons](#), public domain

This famous handscroll copies a lost Tang-dynasty painting by Zhang Xuan. It follows women of the court through the finishing of new silk: beating it on a stone, sewing, and stretching and smoothing it. The section shown here is the stretching and pressing of a length of silk, painted, fittingly, on silk itself.

Look closely

- Find the length of silk. How many women hold it, and why must it be held so evenly?
- Find the pan or iron. How is it heated, and how is it held?
- Find the child. What is the child doing, and why might children have been part of this work?
- Look at the patterns on the women's gowns. Which might be woven and which embroidered?

Talk about it

1. Stretching and pressing new silk smooths and sets it. What does heat do to the protein chains that lets silk be pressed?
2. This painting is itself on silk, about nine hundred years old. What care would a museum give it, knowing silk's weaknesses?

3. What does the scene tell you about how much work went into one length of finished silk?

Safety first. Burn tests are done with a parent beside you: a ½-inch snippet in tweezers over a metal pan or sink, water at hand, hair tied back, synthetics kept away from your face. The bleach test is done **by your parent**, wearing gloves, in a labeled glass jar by an open window: plain chlorine bleach only, never mixed with anything else, especially not ammonia or vinegar, and poured down the drain with running water afterward.

STUDIO LAB

Protein Fiber Detective: Burn, Bleach and Care

Question: Can a burn test and a bleach test tell silk and wool from look-alike cellulose and polyester fabrics? You will extend your burn chart to protein fibers and watch, safely, why care labels forbid chlorine bleach on silk and wool.

You will need

- Snippets of silk (an old scarf or tie), wool, polyester satin or “silky” lining, rayon or acetate lining if available, and cotton
- The burn-test setup from Lesson 1.5 (tweezers, metal pan, water, candle)
- For the parent: gloves, plain liquid chlorine bleach, four small labeled glass jars, a spoon and a timer
- Your identification cards and the 10× magnifier

Steps

1. **Hypothesis.** Predict which snippets will dissolve in bleach and how silk will behave in the flame compared with the polyester satin.
2. With your parent beside you, burn-test silk, wool and polyester satin exactly as in Lesson 1.5, recording approach, flame, removal, smell and residue.
3. Compare silk with wool. Both are protein: what is the same, and what differs (speed, smell, bead)?
4. **Bleach test (parent only).** Your parent puts a 1-inch snippet of silk, wool, cotton and polyester each in its own labeled jar and covers each with undiluted chlorine bleach, by an open window, wearing gloves.
5. Observe from a step back every 10 minutes for an hour, and again after 4 hours. Record what happens to each snippet: unchanged, faded, swelling, falling apart, gone.
6. Your parent pours the jars out into the sink with plenty of running water and rinses them.
7. Make identification cards for silk and wool, with burn residue and bleach result.
8. **Conclude.** Which fibers dissolved? How does that explain the care label on a wool sweater or silk tie?
9. **Repeat round.** Get an unknown “silky” fabric from your parent and identify it with the burn test and the magnifier alone.

Tips

- Silk often burns a little more readily than wool but still self-extinguishes; both smell of burning hair or feathers.
- Polyester satin and acetate lining are the classic silk imposters. Acetate melts and smells sharp, like vinegar.
- The bleach test is slow at first; protein fibers may take an hour or more to disappear completely. Patience is part of the result.

Check your work

- ☐ I burn-tested with my parent beside me, and my parent alone handled the bleach.
- ☐ I recorded burn and bleach behavior for each fiber with times.
- ☐ I made silk and wool identification cards and explained the care-label rule from my evidence.

LAB NOTEBOOK

1. Draw a silk filament in cross-section: two rounded triangles of fibroin inside a coat of sericin. Then draw it after degumming.
2. Make a timeline from the Leizu legend to Justinian's monks, marking which items are legend and which are record.
3. Write care instructions for a silk scarf and a wool sweater side by side, with a reason for each instruction.

KEY FORMULAS

$$\text{degumming loss} = \frac{m_{\text{raw}} - m_{\text{degummed}}}{m_{\text{raw}}} \times 100\%$$

$$\text{degumming loss} = m_{\text{raw}} - m_{\text{degummed}} \times 100\%$$

$$\text{denier} = \text{grams per 9,000 m}$$

$$\text{denier} = \text{grams per 9,000 m}$$

From history. The phrase Silk Road was coined only in 1877, by the German geographer Ferdinand von Richthofen. The ancient routes themselves were never one road but a web of caravan paths and sea lanes, and they carried paper, spices, glass, ideas and the gospel as well as silk.

WORKED EXAMPLES

Example 1. A skein of raw silk weighs 50.0 g. After degumming it weighs 38.5 g. Find the degumming loss.

Show solution

1. Loss: $50.0 - 38.5 = 11.5 \text{ g}$
2. Percent: $\frac{11.5 \text{ g}}{50.0 \text{ g}} \times 100\% = 23\%$

Answer: 23%, typical of the sericin content of raw silk.

Example 2. A reeled cocoon filament is 900 m long and weighs 0.25 g. Find its denier. If 8 such filaments are reeled together, what is the denier of the raw silk thread?

Show solution

1. Denier is grams per 9,000 m: $0.25 \text{ g} \times \frac{9,000 \text{ m}}{900 \text{ m}} = 2.5 \text{ denier}$
2. Eight together: $8 \times 2.5 = 20 \text{ denier}$

Answer: Each filament is 2.5 denier; the reeled thread is about 20 denier. Unit 4 will use denier for every fiber.

Example 3. A silk scarf weighs 40 g after degumming. Assuming each cocoon gives 0.25 g of raw reeled silk and degumming loses 23%, about how many cocoons were reeled?

Show solution

1. Raw silk needed: $\frac{40 \text{ g}}{1 - 0.23} = 51.9 \text{ g}$
2. Cocoons: $\frac{51.9 \text{ g}}{0.25 \text{ g/cocoon}} = 208$

Answer: About 210 cocoons, on these assumptions.

PRACTICE

1. Easy What does the silkworm eat?

Show answer

Mulberry leaves.

2. Easy Name silk's two proteins and say which one is removed in degumming.

Show answer

Fibroin and sericin; sericin is removed.

3. Easy Who is said to have brought silkworm eggs to Justinian, and about when?

Show answer

Monks, around AD 552, hiding the eggs in hollow canes.

4. **Medium** Raw silk weighing 80 g degums to 61 g. Find the loss.

Show answer

$$19/80 \times 100\% \approx 23.8\% \quad 19/80 \times 100\% \approx 23.8\%$$

5. **Medium** A 1,200 m filament weighs 0.30 g. Find its denier.

Show answer

$$0.30 \times 9,000/1,200 = 2.25 \quad 0.30 \times 9,000/1,200 = 2.25 \text{ denier.}$$

6. **Medium** Why does silk shimmer?

Show answer

Its smooth fibroin strands have a rounded triangular cross-section that reflects and scatters light like a prism.

7. **Medium** Which part of the Leizu story is legend, and what does archaeology actually show?

Show answer

The cocoon falling into the empress's tea is legend; archaeology shows silk was made in China thousands of years ago.

8. **Hard** Explain why chlorine bleach is forbidden on silk and wool but often used on white cotton.

Show answer

Hypochlorite attacks and dissolves protein fibers (breaking the peptide chains); cellulose resists it at normal laundry strength.

9. **Hard** A raw silk thread is reeled from 7 filaments of 2.8 denier. What is its denier, and how many grams would 9,000 m weigh?

Show answer

$$7 \times 2.8 = 19.6 \quad 7 \times 2.8 = 19.6 \text{ denier; } 19.6 \text{ g.}$$

10. **Hard** Silk tie A is labeled 100% silk; tie B “silky satin” is polyester. Describe the burn test result you would expect from each.

Show answer

A: burns slowly, sputters, smells of burning hair, self-extinguishes, leaves a crushable black bead. B: shrinks from the flame, melts and drips, chemical smell, hard bead.

11. **Challenge** Reeled silk requires heating the cocoon before the moth emerges; wild (tussah) silk is spun from cocoons the moth has left. Explain how this difference shows up in the yarn and cloth.

Show answer

Reeled silk is long continuous filament, smooth, fine and very lustrous. Tussah cocoons are broken where the moth exits, so the fiber is shorter and must be spun like staple, giving a thicker, more textured, less lustrous yarn, often honey-colored.

COMMON MISTAKES

- Telling the Leizu story as history. It is a legend; say so.
- Using chlorine bleach to whiten a silk or wool garment. It dissolves them.
- Assuming anything shiny is silk. Polyester, acetate and rayon satins look much alike; test before you trust.

Make it a game · Imposter Satin. A parent lines up five shiny fabrics, only one or two of which are real silk. Players get one minute to look, feel, crumple and warm each in their hands (silk warms quickly to the touch) before secretly choosing the real silk. One point for each correct call. Then confirm with a burn test of one snippet, with a parent beside you.

Scripture. “She maketh herself coverings of tapestry; her clothing is silk and purple.” (Proverbs 31:22, KJV)

Silk and purple were the costliest cloth of the ancient world, and the capable woman of Proverbs wears them as the fruit of her diligent work. Fine materials honor the skill and care it takes to make and keep them.

UNIT 2 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (7 pts)
Name the three parts of a wool fiber and give the job of each.
2. (7 pts)
Explain how keratin's structure makes wool resilient and wrinkle-resistant.
3. (7 pts)
A 20.0 g dry wool sample weighs 23.0 g after conditioning. Find its regain, and the water in a 3.5 kg fleece at that regain.
4. (7 pts)
A greasy fleece of 6.0 kg yields 3.6 kg of clean wool. Find the clean yield, and the clean price if greasy wool sells at \$5.40 per kg.
5. (7 pts)
Why does wool coarser than about 30 μm prickle, and what is the comfort factor?
6. (7 pts)
Tell the story of the Macarthurs and merino sheep in two or three sentences.
7. (7 pts)
List the four conditions for felting and explain the directional friction effect.
8. (7 pts)
A 10×10 cm square felts to 7.0×8.0 cm. Find the length, width and area shrinkage.
9. (7 pts)
A felted coaster must finish 4 in square; your swatch shrinks 25% each way. What size do you knit?
10. (6 pts)
How does superwash treatment work, and what is its trade-off?
11. (6 pts)
Compare mohair, cashmere and alpaca: one distinctive property and its structural cause for each.
12. (6 pts)
A jar cools from 62 °C to 50 °C in 40 minutes. Find the cooling rate. Another cools at 0.45 °C/min. Which wrap insulates better?
13. (6 pts)
Raw silk of 64 g degums to 49 g. Find the degumming loss, and name the protein removed.
14. (6 pts)
A 750 m silk filament weighs 0.20 g. Find its denier.
15. (7 pts)
Short essay (5–7 sentences): Write the story of silk from legend to Justinian, clearly marking what is legend and what is record, and explain how the secret of silk was finally carried west.

UNIT PROJECT: ANIMAL FIBERS: IDENTIFICATION PAGES AND A FELTED PIECE

Add animal-fiber pages to your identification kit: cards for wool, silk and at least two specialty fibers or blends, each with swatch, loose fibers, burn residue, magnifier notes and care rules, plus a summary chart of your regain, yield, shrinkage and cooling data.

Make one useful felted piece to a planned size, a coaster set, a needle book, a pot holder or a pair of slipper soles, from wool you shrank on purpose, and write its planning calculation and its actual finished size on a tag.

LOOK FOR	WHAT IT MEANS
Safety	Burn tests were done with a parent beside you, and your parent alone handled bleach; the kit records it.
Accurate identification and care	Cards are correct and complete, with care rules that follow from the fiber's chemistry.
Data and math	Regain, yield, shrinkage and cooling results are reported with units and correct calculations.
Felted piece	The piece is useful, evenly felted, and within about ¼ inch of its planned size, or the miss is honestly explained.
Honest records	Surprises, failed trials and repeat rounds are recorded.

ANSWER KEY

1. Cuticle: overlapping scales with a waxy skin that sheds liquid water and causes felting. Cortex: keratin cells that give strength, elasticity and crimp. Medulla (coarse fibers): hollow core adding lightness and insulation.
2. Its chains are coiled into helices tied together by disulfide bonds, salt links and hydrogen bonds; stretched, the coils straighten, and released, the cross-links pull them back.
3. $3.0/20.0 = 15\%$; $3.0/20.0 = 15\%$; $3.5 \times 0.15 = 0.525$ kg; $3.5 \times 0.15 = 0.525$ kg of water.
4. 60% ; $5.40/0.60 = \$9.00$; $5.40/0.60 = \$9.00$ per clean kg.
5. Coarse fiber ends are too stiff to buckle against the skin, so they poke nerve endings. Comfort factor: the percent of fibers $30\text{ }\mu\text{m}$ or finer.
6. Merinos from southern Africa reached New South Wales in 1797. John and Elizabeth Macarthur bred them for fine wool, and Elizabeth managed the flock during John's long absences in England, helping begin Australia's fine-wool industry.
7. Moisture, heat, soap or alkali, agitation. The scales let a fiber slide root-first more easily than tip-first, so agitation ratchets fibers in one direction until they lock together.
8. Length 30% , width 20% ; area $(1 - 56/100) \times 100\% = 44\%$; $(1 - 56/100) \times 100\% = 44\%$.
9. $4/0.75 \approx 5.33$ in; $4/0.75 \approx 5.33$ in square.
10. Chlorine treatment and a thin polymer coating smooth or mask the scales so they cannot catch; the wool machine-washes without felting but can never be felted on purpose.
11. Mohair: luster, from thin flat scales. Cashmere: softness, from very fine ($\leq 19\text{ }\mu\text{m}$) fibers with thin scales. Alpaca: light warmth, from partly hollow medullated fibers (and little grease).
12. $12/40 = 0.30\text{ }^{\circ}\text{C/min}$; $12/40 = 0.30\text{ }^{\circ}\text{C/min}$; the first wrap insulates better.
13. $15/64 \times 100\% \approx 23.4\%$; $15/64 \times 100\% \approx 23.4\%$; sericin.
14. $0.20 \times 9,000/750 = 2.40$; $0.20 \times 9,000/750 = 2.4$ denier.
15. A good answer tells the Leizu legend as legend, notes archaeological evidence of very early Chinese silk, the long Chinese monopoly and the Silk Road trade, and Procopius's account of monks bringing silkworm eggs in hollow canes to Justinian around AD 552, founding Byzantine silk production.

MANUFACTURED FIBERS

For most of history every fiber grew on a plant or an animal. In the 1880s chemists began to make fibers: first by dissolving the cellulose of wood and squirting it back out as filaments (rayon), then, in the 1930s, by building long chain molecules from small ones (nylon, polyester, acrylic and, in 1958, spandex). Today most of the fiber the world uses is made in factories. This unit explains how: the chemistry of each polymer, the three ways of spinning a liquid into a fiber (wet, dry and melt), why drawing a fiber makes it strong, and the difference between endless filament and cut staple.

Manufactured fibers are neither villains nor miracles. Polyester is strong, quick-drying and wrinkle-resistant but holds oily odors and melts; nylon is the toughest common fiber but yellows in sunlight; rayon drapes and absorbs beautifully but is weak when wet. You will measure those properties yourself: wet and dry strength of rayon, abrasion resistance of nylon, moisture regain and drying time of five fibers, stretch and recovery of spandex blends, and a final burn-test challenge that completes your identification kit. The unit ends with a fair verdict, fiber by fiber, written from your own data.

PREREQUISITES

- Units 1–2: cellulose, keratin, moisture regain and the burn test
- Comfortable with percents, ratios and simple formulas
- A parent available for the Lesson 3.5 burn tests

MASTERY CHECKLIST

- ☐ I can explain the difference between regenerated fibers (rayon, lyocell) and synthetic fibers (nylon, polyester, acrylic, spandex).
- ☐ I can describe wet, dry and melt spinning, and why drawing aligns polymer chains and makes a fiber stronger.
- ☐ I can calculate wet-strength retention, molar mass from degree of polymerization, drying rate, elongation and recovery, and filament diameter from denier.
- ☐ I can tell the stories of Chardonnet, Cross and Bevan, Carothers, Whinfield and Dickson, and Shivers accurately.
- ☐ I can state real strengths and real weaknesses of each manufactured fiber, fairly, and choose fibers or blends for a job.
- ☐ I can identify manufactured fibers by burn test safely, with a parent beside me.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **A labeled swatch set of manufactured fabrics:** Thrift-store linings, sports jerseys, fleece, stretch denim and rayon blouses give you rayon, acetate, nylon, polyester, acrylic and spandex blends for pennies. Always check the fiber label before cutting.
- **Medium-grit sandpaper and a wooden block:** For the Lesson 3.2 home abrasion test.
- **A spring scale or luggage scale:** Optional. Reads stretching force directly for the Lesson 3.4 stretch test; a bucket and water bottles work too.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

3.1 Chardonnet's Silk and the Viscose Process	3 sessions of 50 minutes
3.2 Carothers and Nylon 6,6	3 sessions of 50 minutes
3.3 Polyester, Acrylic and the Spinneret	3 sessions of 50 minutes
3.4 Shivers's Spandex and the Science of Stretch	3 sessions of 50 minutes
3.5 Microfibers, Blends and the Fair Verdict	3 sessions of 50 minutes

3.1 CHARDONNET'S SILK AND THE VISCOSE PROCESS

OBJECTIVES

- Tell how Chardonnet, then Cross, Bevan and Beadle, learned to make fibers from wood cellulose, and how lyocell improved the process.
- Describe the viscose process step by step and explain why rayon is weak when wet.
- Measure wet and dry strength of rayon and cotton and calculate wet-strength retention and molar mass from degree of polymerization.

Warm-up. Find a rayon or viscose garment (a soft blouse, a lining, a summer shirt; check the label) and a cotton one of similar weight. Compare how each hangs from your hand, and how each feels. Then guess: if both came from plants, why do they feel so different?

WATCH

Synthetic Fibers: Nylon and Rayon (1949)

US Auto Industry • 13:13

https://www.youtube.com/watch?v=K0aF1qao_8Y

WHEN TO WATCH

After “How they figured it out.” This 1949 classroom film follows wood pulp through a rayon plant and then makes nylon; name each stage as it appears.

Note: An Encyclopaedia Britannica educational film from 1949; its figures reflect that time, but the processes it shows are still the basis of the industry.

BACKUP VIDEO

From wood cellulose to textile fibres

Tampere University of Technology • 2:53

<https://www.youtube.com/watch?v=GQM0DJ2t9E0>

A short look at how wood cellulose is dissolved and spun anew, from a university research lab.

KEY TERMS

regenerated fiber

A fiber made by dissolving a natural polymer (usually cellulose from wood) and re-forming it as filaments. Rayon, modal, lyocell and acetate are made this way.

spinneret

A metal plate pierced with tiny holes through which a liquid polymer is forced to form filaments.

degree of polymerization (DP)

The number of repeating units in one polymer chain. Cotton cellulose often has a DP around 10,000; viscose rayon only a few hundred.

viscose

The thick, honey-like solution of cellulose xanthate in dilute sodium hydroxide from which most rayon is spun; also a common name for rayon itself.

wet spinning

Spinning a polymer solution into a liquid bath that turns it solid; rayon is wet-spun into an acid bath.

lyocell

A regenerated cellulose fiber spun from a solution in a recyclable organic solvent; stronger when wet than ordinary rayon.

CORE IDEAS

The story. In the 1870s the young Count Hilaire de Chardonnet helped Louis Pasteur study a disease that was killing France's silkworms. Watching the worms, he wondered whether people could make silk without them. In 1884 he patented a fiber made by dissolving nitrocellulose (cellulose treated with nitric acid) and drawing the solution through fine tubes. His “Chardonnet silk” was a sensation at the Paris Exposition of 1889, and in 1891 he opened a factory at Besançon. It shone like silk, but nitrocellulose is dangerously flammable, and the fiber had to be chemically treated afterward to make it safe to wear.

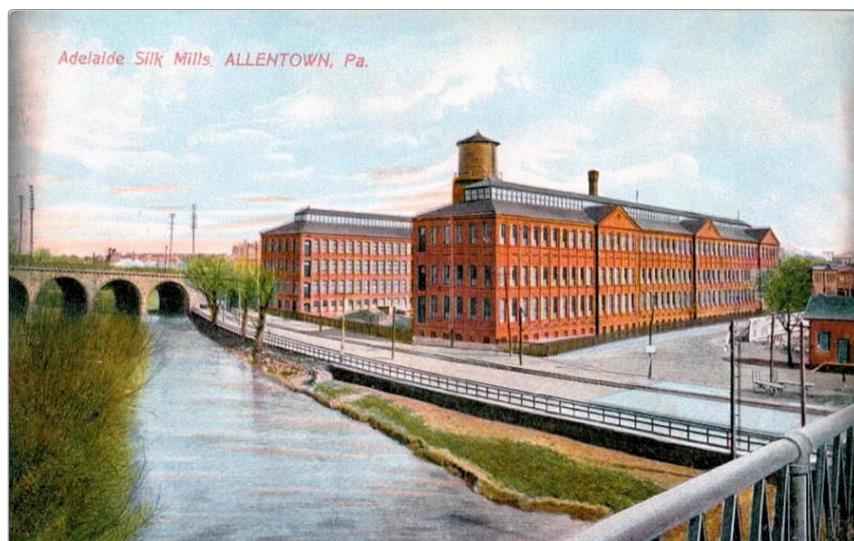
How they figured it out. A safer and cheaper route came from England. In 1892 the chemists Charles Cross, Edward Bevan and Clayton Beadle patented the viscose process. Wood pulp, nearly pure cellulose, is steeped in sodium hydroxide, crumbled and aged, then treated with carbon disulfide to form cellulose xanthate, which dissolves in dilute caustic soda into a thick orange-brown liquid they called viscose for its viscosity. Forced through a spinneret into a bath of sulfuric acid and salts, the viscose turns back into solid cellulose filaments. The British firm Courtaulds bought the rights in 1904, the American Viscose Company began spinning in Pennsylvania in 1910, and in 1924 American makers agreed on the name *rayon*.

The fabric science. Rayon is cellulose, the same molecule as cotton, so it absorbs water well (regain about 11 to 13 percent), dyes brilliantly and burns like paper. But dissolving and re-forming chops the chains short: a degree of polymerization of a few hundred instead of cotton's thousands, and much less crystalline order. Water slips easily between the loosely packed chains, pries them apart and lets them slide. So ordinary rayon loses a third to half of its strength when wet, stretches out of shape, and may shrink in hot washing. That is why many rayon garments say dry clean or hand wash, and why a wet rayon blouse must be handled gently. In return, its soft, slippery filaments drape and flow like silk at a fraction of silk's price.

Better versions. Chemists kept improving the process. High-wet-modulus rayons such as modal are spun under different conditions to keep longer chains and more order, so they hold their shape when wet. *Lyocell*, developed by Courtaulds in the 1980s and sold from the early 1990s, skips the xanthate step entirely: wood cellulose dissolves directly in an organic solvent (N-methylmorpholine N-oxide), which is recovered and reused almost completely. Lyocell is strong wet and dry, absorbent and smooth, though its fibers can split into tiny surface fibrils that give a peach-skin feel. The viscose process itself uses carbon disulfide, a chemical that must be tightly controlled because it harms workers' health; modern plants enclose and recover it.

The studio lab. You will test the lesson's central claim. Identical strips of rayon and cotton fabric will be loaded dry and wet until they tear, and you will calculate how much strength each keeps when wet. You will also measure how much each shrinks after one hot wash.

PICTURE STUDY



Adelaide Silk Mill, Unknown publisher, c. 1910 · Colored postcard · Allentown, Pennsylvania; image from Wikimedia Commons (public domain)

Image: [Wikimedia Commons](#), public domain

In 1910, the year the American Viscose Company began making rayon in Pennsylvania, the same state was full of silk mills like this one in Allentown, which threw and wove imported raw silk. Rayon was invented as “artificial silk” to compete with exactly this cloth, and within a few decades many such mills were weaving rayon instead.

Look closely

- Look at the size of the building and count the rows of windows. Why would a mill need so much daylight?
- Find any chimneys or power sources. How was this mill likely powered?
- Look for people, wagons or rail lines. How did raw silk arrive and cloth leave?
- Imagine the floors inside. Which machines from this unit and the next would you expect to find?

Talk about it

1. Silk cost far more than rayon would. Why would a mill owner of 1925 be tempted to switch to rayon?
2. What might the workers in this mill have thought about “artificial silk”?
3. How does a mill like this connect to the history of Slater and Lowell in Unit 4?

Safety first. Hang test weights over a soft surface and keep feet clear of the bucket. The hot wash in this lab is done in the family washer with a parent's permission. The viscose process uses hazardous chemicals and is described here, never tried at home.

STUDIO LAB

Rayon Wet and Dry: The Strip Test

Question: How much of its strength does rayon keep when wet, compared with cotton? You will load fabric strips until they tear, dry and wet, and calculate wet-strength retention. A shrinkage check rounds out the lab.

You will need

- About ¼ yard each of a light woven rayon (challis or a thrift-store blouse) and a cotton of similar weight (lawn, voile or a shirt)
- The dowel and bucket rig from Unit 1, a gallon jug or extra water bottles, and the scale
- Two large binder clips or bulldog clips per test, a ruler and a fabric marker
- A bowl of water and a timer

FABRIC TEST STRIPS

Finished size: Six strips per fabric, each 1 × 8 in (2.5 × 20 cm), plus one 8 × 8 in (20 × 20 cm) shrinkage square · About 25 minutes

Fabric and notions

- Woven rayon and woven cotton of similar weight, ¼ yard each
- A permanent fabric marker, a clear ruler and sharp shears or a rotary cutter and mat

How to make it

1. Press both fabrics flat and find the lengthwise grain (parallel to the selvage) on each.
2. Cut six strips of each fabric, 1¼ in wide by 8 in long, with the long side on the lengthwise grain.
3. Fray each strip down to exactly 1 in wide by pulling out lengthwise yarns from both edges; this makes every strip carry the same number of yarns.
4. Mark a 4 in test length in the middle of each strip; the clips will grip outside the marks.
5. Cut one 8 × 8 in square of each fabric and mark a 20 × 20 cm square on it for the shrinkage test. Label everything.

Fabric check: Choose plain-weave fabrics of similar thickness so the fiber, not the weave, is the difference. Thrift-store rayon blouses (check the label: rayon or viscose, 100%) are ideal. Avoid rayon blends with polyester, which hide the effect.

Steps

1. **Hypothesis.** Predict each fabric's wet-strength retention as a percent.
2. Soak three strips of each fabric in water for 10 minutes; keep the other three dry.
3. Clamp a dry strip to the dowel with one binder clip at the top mark and hang the bucket from a second clip at the bottom mark.
4. Fill the bucket slowly with water, a cup at a time, until the strip tears. Weigh the bucket and water. Record the breaking load and where it broke.
5. Repeat for every dry and wet strip, testing wet strips straight from the bowl.
6. Calculate the mean dry and wet breaking loads and the wet-strength retention for each fabric.
7. **Shrinkage.** Wash both squares in hot water with a regular load and tumble dry. Measure the marked squares and calculate length, width and area shrinkage.
8. **Conclude.** Did the data match the lesson? Does the rayon's care label make more sense now?

9. **Repeat round.** If any strip slipped out of a clip or broke at a clip edge, discard it, fold a scrap of cardboard into the clip jaws as padding, and test a fresh strip.

Tips

- If the strips are too strong for your bucket, fray them narrower (½ in) and test all strips at the same new width.
- A luggage scale hooked between the dowel and the bucket gives a reading at the moment of breaking, if you watch closely.
- Real textile labs run this as a grab or strip test on a machine that pulls at a steady speed; your bucket is a slow, simple version of the same idea.

Check your work

- ☐ I used strips of equal width and length on the same grain, so only fiber and wetness changed.
- ☐ I reported means, retention percentages and shrinkage with units.
- ☐ I discarded and replaced any test that failed at the clip and said so.

LAB NOTEBOOK

1. Draw the viscose process as a flowchart from tree to fabric, with the chemical added at each step.
2. Sketch short, loosely packed rayon chains beside long, ordered cotton chains, with water molecules slipping between the rayon chains.
3. Tape a dry and a torn wet rayon strip under your results table.

KEY FORMULAS

$$\text{wet-strength retention} = \frac{\text{wet breaking load}}{\text{dry breaking load}} \times 100\%$$

$$\text{wet-strength retention} = \frac{\text{wet breaking load}}{\text{dry breaking load}} \times 100\%$$

$$M = DP \times 162 \text{ g/mol} \quad (\text{for cellulose, one glucose unit} = 162 \text{ g/mol})$$

$$M = DP \times 162 \text{ g/mol} \quad (\text{for cellulose, one glucose unit} = 162 \text{ g/mol})$$

From history. Rayon changed the clothing of ordinary families in the 1920s and 1930s: dresses, linings and stockings with the look of silk became affordable to millions. During World War II, rayon tire cord also replaced cotton in many truck and airplane tires because it ran cooler and lasted longer.

WORKED EXAMPLES

Example 1. Rayon strips broke at a mean of 9.6 kg dry and 5.3 kg wet; cotton strips at 11.2 kg dry and 12.9 kg wet. Find each wet-strength retention.

Show solution

1. Rayon: $\frac{5.3 \text{ kg}}{9.6 \text{ kg}} \times 100\% = 55\%$ $\frac{5.3 \text{ kg}}{9.6 \text{ kg}} \times 100\% = 55\%$

2. Cotton: $\frac{12.9 \text{ kg}}{11.2 \text{ kg}} \times 100\% = 115\%$ $\frac{12.9 \text{ kg}}{11.2 \text{ kg}} \times 100\% = 115\%$

Answer: Rayon kept 55% of its strength wet; cotton gained, holding 115%. Same molecule, opposite behavior, because of chain length and order.

Example 2. Find the molar mass of a cellulose chain with DP 10,000 (cotton) and DP 300 (viscose rayon). How many times longer is the cotton chain?

Show solution

1. Cotton: $10,000 \times 162 \text{ g/mol} = 1,620,000 \text{ g/mol}$ $10,000 \times 162 \text{ g/mol} = 1,620,000 \text{ g/mol}$

2. Rayon: $300 \times 162 \text{ g/mol} = 48,600 \text{ g/mol}$ $300 \times 162 \text{ g/mol} = 48,600 \text{ g/mol}$

3. Ratio: $10,000 \div 300 \approx 33$ $1,620,000 \div 48,600 \approx 33$

Answer: 1.62 million g/mol against 48,600 g/mol: the cotton chain is about 33 times longer.

Example 3. A 20.0×20.0 cm rayon swatch measures 18.6×19.4 cm after one hot wash and tumble dry. Find the length, width and area shrinkage.

Show solution

1. Length: $\frac{20.0 - 18.6}{20.0} \times 100\% = 7\%$
 $\frac{20.0 - 18.6}{20.0} \times 100\% = 7\%$.
2. Width: $\frac{20.0 - 19.4}{20.0} \times 100\% = 3\%$
 $\frac{20.0 - 19.4}{20.0} \times 100\% = 3\%$.
3. Area: $\left(1 - \frac{18.6 \times 19.4}{400}\right) \times 100\% = 9.8\%$
 $\left(1 - \frac{18.6 \times 19.4}{400}\right) \times 100\% = 9.8\%$.

Answer: 7% in length, 3% in width, about 10% in area: wash rayon cool and dry it flat.

PRACTICE

1. **Easy** From what raw material is most rayon made?

Show answer

Wood pulp (cellulose).

2. **Easy** Who patented the viscose process, and in what year?

Show answer

Charles Cross, Edward Bevan and Clayton Beadle, 1892.

3. **Easy** Name the three spinning methods for manufactured fibers. Which one makes rayon?

Show answer

Wet, dry and melt spinning; rayon is wet-spun.

4. **Medium** A rayon yarn breaks at 440 g dry and 240 g wet. Find its wet-strength retention.

Show answer

$$240/440 \times 100\% \approx 55\% \quad 240/440 \times 100\% \approx 55\%$$

5. **Medium** Find the molar mass of a cellulose chain of DP 500.

Show answer

$$500 \times 162 = 81,000 \text{ g/mol} \quad 500 \times 162 = 81,000 \text{ g/mol}$$

6. **Medium** Why is rayon weaker wet than dry, while cotton is stronger wet?

Show answer

Rayon's short chains and low crystallinity let water push chains apart so they slide; cotton's long, highly ordered chains hold, and swelling evens out its stress.

7. **Medium** What is the main improvement of lyocell over the viscose process?

Show answer

Cellulose dissolves directly in a solvent that is recovered and reused, with no carbon disulfide, and the fiber is strong when wet.

8. **Hard** A lining's label says "dry clean." Using this lesson, give two reasons a maker might say that about a rayon lining.

Show answer

Wet rayon loses much of its strength and stretches out of shape, and it can shrink in hot water; dry cleaning avoids water.

9. **Hard** A rayon swatch shrinks 6% in length and 4% in width. Find the area shrinkage.

Show answer

$$(1 - 0.06 \times 0.96) \times 100\% \approx 9.8\% \quad (1 - 0.06 \times 0.96) \times 100\% \approx 9.8\%$$

10. **Hard** Chardonnet's first fiber had to be treated after spinning before it could be worn. Why?

Show answer

It was nitrocellulose, which is extremely flammable; it was denitrated back toward ordinary cellulose to make it safe.

11. **Challenge** A 55% wet-strength retention sounds bad. Explain why rayon is still an excellent choice for some garments, and for which ones you would avoid it.

Show answer

It drapes beautifully, absorbs sweat, dyes richly and costs far less than silk; good for blouses, linings and dresses worn and washed gently. Avoid it for work clothes, towels or anything scrubbed and wrung hard when wet.

COMMON MISTAKES

- Calling rayon a synthetic. It is regenerated cellulose: a natural polymer re-formed by people.
- Wringing a wet rayon garment. Press water out gently in a towel; wet rayon stretches and tears.
- Assuming all rayons are alike. Modal and lyocell are made to hold their strength wet.

Make it a game · Silk or Not? A parent sets out four smooth, shiny fabrics: silk, rayon, acetate and polyester. Each player handles them blindfolded for 30 seconds each and assigns a fiber name. Then everyone drips one drop of water on each: rayon and silk darken and absorb quickly, polyester and acetate let it bead. Two points for each correct blind call, one for a correct call after the water clue.

3.2 CAROTHERS AND NYLON 6,6

OBJECTIVES

- Tell the story of Wallace Carothers's polymer research at DuPont and the invention of nylon 6,6 in 1935.
- Explain condensation polymerization, the amide link, melt spinning and cold drawing, and how they make nylon strong and tough.
- Measure abrasion resistance and calculate repeat-unit molar mass, draw ratio and denier change.

Warm-up. List every nylon thing you can find in ten minutes: zippers, backpack fabric, rope, toothbrush bristles, jacket shells, sock heels, fishing line, tent fabric. Which jobs do they share?

WATCH

How Nylon Was Discovered - Christmas Lectures with George Porter

[The Royal Institution](#) · 4:00

<https://www.youtube.com/watch?v=1fnHKatL-68>

WHEN TO WATCH

After “How they figured it out.” Watch nylon being drawn from the boundary between two liquids, and listen for why the chain grows so long.

BACKUP VIDEO

The chemistry of nylon

[College of Science and Engineering, UMN](#) · 3:05

https://www.youtube.com/watch?v=3ndzkma1V_k

A short chemistry explanation of how the nylon chain is built and why it is so strong.

KEY TERMS

synthetic fiber

A fiber made from a polymer that chemists build from small molecules, usually from petroleum or natural gas: nylon, polyester, acrylic, spandex, olefin.

amide link

The $-\text{CO}-\text{NH}-$ group that joins units in nylon (and, in a different form, in wool and silk proteins); amide groups on neighboring chains hydrogen-bond strongly.

drawing

Stretching a newly spun filament to several times its length so the chains line up and crystallize, making it much stronger.

condensation polymerization

Joining monomers into a chain by a reaction that also releases a small molecule, usually water.

melt spinning

Melting a polymer and pumping it through a spinneret; the filaments harden as they cool in air.

abrasion resistance

A fabric's ability to withstand rubbing without wearing through.

CORE IDEAS

The story. In 1928 the DuPont company hired Wallace Carothers, a quiet young chemistry instructor from Harvard, to do pure research at its Experimental Station in Wilmington, Delaware. His question was basic science: were polymers really giant chain molecules, and could he build them on purpose? He could. In 1930 his team made the first neoprene rubber and long polyester chains. Then, on February 28, 1935, his colleague Gerard Berchet, working under his direction, made a polymer from two six-carbon molecules. It would become nylon 6,6, and it changed the world's clothing.

How they figured it out. The key discovery came by accident in 1930. The chemist Julian Hill, in Carothers's group, poked a glass rod into a blob of molten polymer and pulled out a thread. When he stretched the cooled thread, it suddenly grew much longer, thinner, glossier and far stronger: cold drawing. The first polyesters melted too low to be useful, but nylon 6,6, with its higher melting point,

could be melt-spun and drawn into a strong, silky fiber. DuPont spent millions turning it into a product. The first nylon product, toothbrush bristles, appeared in 1938. Nylon stockings were shown at the 1939 New York World's Fair and went on sale nationwide on May 15, 1940, and sold out in days. Then war came, and nearly all nylon went to parachutes, tents, ropes and tire cords.

The fabric science. Nylon 6,6 is made from hexamethylenediamine and adipic acid, each with six carbons (hence 6,6). The amine end of one reacts with the acid end of the other to form an amide link, -CO-NH- , and releases a molecule of water: condensation polymerization. Repeated thousands of times, it builds long, flexible chains. The amide groups hydrogen-bond to neighboring chains, much as silk's do. In the freshly spun filament the chains are tangled; drawing pulls them parallel so they pack into crystals and bear load together. The result is the strongest, toughest and most abrasion-resistant of the common fibers, with good stretch and recovery.

Fairly stated. Nylon's weaknesses are real too. Its regain is only about 4 percent, so it feels clammy in heat and builds static in dry air. Sunlight's ultraviolet rays slowly weaken and yellow it. It melts at about 260°C (500°F), so a hot iron can glaze or melt it and sparks can burn holes. It can pill, and white nylon picks up color from other clothes in the wash. And like other synthetics, it is made from petroleum and natural gas. A good textile scientist uses nylon where its toughness matters most: backpacks, sock heels, rope, zippers, outerwear, and thread for heavy work.

The studio lab. You will put toughness to a test. Swatches of nylon, cotton, polyester and wool are rubbed with sandpaper under the same weight, stroke by stroke, until the first yarn breaks. The number of strokes is the fabric's abrasion score, a simple version of the machines that rate upholstery and workwear.

PICTURE STUDY



Navy Parachute Rigger Threading an Industrial Sewing Machine, U.S. Navy photographer, Mid-20th century · Photograph · U.S. National Archives (via the Digital Public Library of America)

Image: [Wikimedia Commons](#), public domain

Nylon replaced silk in parachutes during World War II, and nylon parachutes have been sewn and repaired by Navy parachute riggers ever since. This Navy photograph's caption says riggers “become experts in using sewing machines.” A pilot's life could depend on their stitching.

Look closely

- Find the machine's thread path. How many guides and tension points can you see on the way to the needle?
- Look at the rigger's hands. Where are his fingers relative to the needle?
- Look at the size and build of the machine. How does it differ from a home machine?
- Find the caution stripes on the table. Why would a machine shop mark them?

Talk about it

1. Before nylon, parachutes were made of silk, much of it imported from Japan. Why did World War II make nylon urgent?
2. Which of nylon's properties (strength, toughness, light weight, low regain) matter most in a parachute?

3. What does this photograph suggest about the skill that sewing work demanded during the war?

Safety first. Sand away from your body with the swatch clamped or taped down, and wear a dust mask or work outdoors, because fabric dust and sandpaper grit should not be breathed. Wash hands afterward. Keep pins and needles counted in the pincushion.

STUDIO LAB

The Sandpaper Rub Test: Which Fabric Is Toughest?

Question: How many rubs does it take to wear through nylon compared with polyester, wool and cotton fabrics of similar weight? You will build a simple abrasion tester and score each fabric.

You will need

- Swatches about 4 × 4 in of nylon (a backpack or windbreaker scrap), polyester, wool and cotton of similar weight
- Medium-grit (120) sandpaper, a wooden block about 2 × 3 in, and a 1 kg weight (a bag of sugar or a filled water bottle)
- Masking tape, a firm board, a tally counter or pencil, and a dust mask

Steps

1. **Hypothesis.** Rank the four fabrics by expected strokes to failure, and guess nylon's score.
2. Weigh the four swatches to compare fabric weights; record grams per swatch.
3. Wrap the sandpaper around the block and tape it. Tape the first swatch flat and taut to the board.
4. Set the 1 kg weight on the block. Push it straight across the swatch and back: that is one stroke. Use the same stroke length (about 3 in) and speed every time.
5. Count strokes. Check the swatch every 10 strokes; stop when the first yarn breaks or a hole appears. Record the count.
6. Use a fresh strip of sandpaper for each fabric. Test two swatches of each fabric and average.
7. Calculate each fabric's score as a percent of the toughest, and divide strokes by swatch weight for a per-gram comparison.
8. **Conclude.** Rank the fabrics. Did fabric weight or weave affect the result as much as fiber?
9. **Repeat round.** Test a 50/50 cotton/nylon or poly/cotton blend if you have one. Does a little synthetic toughen a natural fiber?

Tips

- Keep the weight centered and do not press down with your hand: the weight supplies the force.
- Sandpaper wears too. If a test runs past 200 strokes, replace the paper every 100 strokes and note it.
- Upholstery fabrics are rated this way by machine in double rubs; a home-décor course uses the same idea.

Check your work

- ☐ I kept weight, stroke length, sandpaper grit and fabric size the same for every test.
- ☐ I tested two swatches of each fabric and reported averages.
- ☐ I considered fabric weight in my conclusion.

LAB NOTEBOOK

1. Draw the condensation reaction: a diamine and a diacid joining at an amide link, with a water molecule leaving. Circle the amide group.
2. Sketch a filament before and after drawing: tangled chains, then parallel chains packed into crystals.
3. Tape in your worn swatches in order of toughness with their stroke counts.

KEY FORMULAS

$$\text{draw ratio} = \frac{\text{length after drawing}}{\text{length before drawing}}$$

$$\text{draw ratio} = \frac{\text{length before drawing}}{\text{length after drawing}}$$

$$\text{denier after} = \frac{\text{denier before}}{\text{draw ratio}}$$

$$\text{denier after} = \text{draw ratio} \times \text{denier before}$$

From history. In Germany, Paul Schlack of IG Farben developed a different nylon, nylon 6, from a single starting molecule (caprolactam) in 1938, partly to work around DuPont's patents. Nylon 6 and nylon 6,6 behave much alike and are both made in huge quantities today.

WORKED EXAMPLES

Example 1. The repeat unit of nylon 6,6 is $\text{C}_{12}\text{H}_{22}\text{N}_2\text{O}_2$. Find its molar mass (C 12.01, H 1.008, N 14.01, O 16.00 g/mol), and the molar mass of a chain of 100 repeat units.

Show solution

$$1. \text{ C: } 12 \times 12.01 = 144.12; 12 \times 12.01 = 144.12; \text{ H: } 22 \times 1.008 = 22.18; 22 \times 1.008 = 22.18; \text{ N: } 2 \times 14.01 = 28.02; 2 \times 14.01 = 28.02; \text{ O: } 2 \times 16.00 = 32.00; 2 \times 16.00 = 32.00.$$

$$2. \text{ Repeat unit: } 144.12 + 22.18 + 28.02 + 32.00 = 226.32 \text{ g/mol}; 144.12 + 22.18 + 28.02 + 32.00 = 226.32 \text{ g/mol}.$$

$$3. \text{ Chain: } 100 \times 226.32 = 22,632 \text{ g/mol}; 100 \times 226.32 = 22,632 \text{ g/mol}.$$

Answer: 226.32 g/mol per repeat unit; a 100-unit chain is about 22,600 g/mol. Each repeat unit released two molecules of water as it formed.

Example 2. A freshly spun nylon filament of 12 denier is drawn from 1.0 m to 4.0 m. Find the draw ratio and the new denier.

Show solution

$$1. \text{ Draw ratio: } \frac{4.0 \text{ m}}{1.0 \text{ m}} = 4.0; 4.0 \text{ m} / 1.0 \text{ m} = 4.0.$$

$$2. \text{ The same mass is spread over four times the length: } \frac{12 \text{ den}}{4.0} = 3.0 \text{ den}; 12 \text{ den} / 4.0 = 3.0 \text{ den}.$$

Answer: Draw ratio 4; the filament becomes 3 denier, finer and much stronger.

Example 3. In the sandpaper test, nylon lasted 240 strokes, polyester 190, wool 70 and cotton 55. Express each as a percent of nylon's score and rank them.

Show solution

$$1. \text{ Polyester: } 190/240 \times 100\% = 79\%; 190/240 \times 100\% = 79\%; \text{ wool: } 70/240 \times 100\% = 29\%; 70/240 \times 100\% = 29\%; \text{ cotton: } 55/240 \times 100\% = 23\%; 55/240 \times 100\% = 23\%.$$

Answer: Nylon 100%, polyester 79%, wool 29%, cotton 23%. Fabric weight and weave also matter, so compare fabrics of similar weight.

PRACTICE

1. **Easy** On what date did Berchet, in Carothers's group, first make nylon 6,6?

Show answer

February 28, 1935.

2. **Easy** What small molecule is released when an amide link forms?

Show answer

Water.

3. **Easy** What was the first nylon product, and when?

Show answer

Toothbrush bristles, 1938.

4. **Medium** A 30-denier filament is drawn 3.5 times. What is its new denier?

Show answer

$30/3.5 \approx 8.630/3.5 \approx 8.6$ denier.

5. **Medium** Why does drawing make a fiber stronger?

Show answer

It pulls tangled chains parallel so they crystallize and share load together.

6. **Medium** Find the molar mass of a nylon 6,6 chain of 150 repeat units.

Show answer

$150 \times 226.32 \approx 33,950$ g/mol $150 \times 226.32 \approx 33,950$ g/mol

7. **Medium** Name two honest weaknesses of nylon and a garment problem each causes.

Show answer

Low regain: clammy shirts and static. UV sensitivity: faded, weakened outdoor gear. (Also melting under a hot iron, pilling.)

8. **Hard** Nylon's amide link also appears in wool and silk. Why might that make nylon dye well with the same acid dyes used for wool?

Show answer

Amide groups and amine chain ends give positive sites in acid dyebaths, which attract and bind negatively charged acid dye molecules, as in wool and silk.

9. **Hard** A rope of 12 strands each 840 denier is all nylon. How many grams does 9,000 m of the rope weigh, and how many grams per meter?

Show answer

$12 \times 840 = 10,080$ g $12 \times 840 = 10,080$ g per 9,000 m; $10,080/9,000 = 1.12$ g/m $10,080/9,000 = 1.12$ g/m.

10. **Hard** A filament must end at 2.5 denier after a draw ratio of 4.2. What denier must it be spun at?

Show answer

$2.5 \times 4.2 = 10.5$ $2.5 \times 4.2 = 10.5$ denier.

11. **Challenge** Carothers was hired for pure research with no product in mind. Using the nylon story, argue whether a company should pay scientists to answer basic questions.

Show answer

A strong answer notes that basic questions about chain molecules led to neoprene, nylon and the whole synthetic-fiber industry, which no product plan would have aimed at; but also that DuPont needed years of applied work and investment to turn the discovery into goods. Both kinds of work were necessary.

COMMON MISTAKES

- Thinking nylon was invented to make stockings. It came from basic research on polymers; stockings were the first big market.
- Ironing nylon on a cotton setting. It glazes and melts; use a low setting and a press cloth.
- Comparing a heavy canvas with a thin nylon and calling the canvas tougher. Compare fabrics of similar weight, or per gram.

Make it a game · Nylon Hunt Countdown. Set a timer for five minutes. Players race through the house listing nylon items with the job each one does (a zipper's teeth, a backpack's shell, a rope). Score one point per item, two if you can name the nylon property that suits the job (toughness, strength, light weight). A parent checks labels for disputed items.

3.3 POLYESTER, ACRYLIC AND THE SPINNERET

OBJECTIVES

- Tell the story of Whinfield and Dickson's polyester (1941) and describe how polyester and acrylic are made.
- Compare melt, wet and dry spinning, filament and staple, and texturing, and explain polyester's resilience, quick drying and oil-holding.
- Measure moisture regain and drying time of five fibers and calculate regain and drying rates.

Warm-up. Read the labels on the family's towels, sheets, fleece jackets and dress shirts. Which are polyester or poly blends? For each one, guess why the maker chose polyester.

WATCH

Polyester Fiber - Production process, Properties and Uses

Textile Vlog · 4:13

https://www.youtube.com/watch?v=z9r_ChCqIB8

WHEN TO WATCH

After “The fabric science.” Follow polyester from monomers to chips to the melt-spinning line and the bales of staple fiber.

Note: A short process overview from a textile-education channel; we use it for its factory footage.

BACKUP VIDEO

Polymer melt spinning

Eric Devaux · 1:24

<https://www.youtube.com/watch?v=cn6K1m7yH0I>

An animation of the melt-spinning line, for review before the practice set.

KEY TERMS

polyester (PET)

Polyethylene terephthalate; a synthetic polymer of terephthalic acid and ethylene glycol joined by ester links; the most widely used manufactured fiber.

dry spinning

Spinning a polymer dissolved in a solvent into warm air, which evaporates the solvent; acetate, spandex and some acrylics are dry-spun.

texturing

Crimping, coiling or looping smooth synthetic filaments with heat so the yarn becomes bulky, soft and stretchy.

acrylic

A synthetic fiber made mostly of polyacrylonitrile, spun from solution; soft, light and wool-like.

filament and staple

Filament: continuous fiber. Staple: fiber cut into short lengths (often 1½ to 3 inches) and crimped so it can be spun like cotton or wool.

oleophilic

Oil-loving. Polyester attracts and holds oily soils and body oils, which is why polyester can keep odors.

CORE IDEAS

The story. Carothers's group had made polyesters first and set them aside because they melted too low. In 1941 two English chemists at the Calico Printers' Association in Manchester, John Rex Whinfield and James Tennant Dickson, read his papers and tried a polyester with a stiff benzene ring in its backbone, made from terephthalic acid and ethylene glycol. It melted high enough to iron and could be drawn into strong fibers. Because of the war, the discovery was kept quiet. Imperial Chemical Industries developed it in Britain as Terylene, and DuPont bought the American rights and sold it as Dacron in the early 1950s. Acrylic arrived at almost the same time: DuPont's Orlon reached the market in 1950 as a light, warm, wool-like fiber.

How they figured it out. Polyester is made by condensation, like nylon, but its links are esters ($-\text{CO}-\text{O}-$). The rigid ring in each repeat unit makes the chain stiff, and that stiffness is the secret of polyester's character. Making the fiber is pure physics: chips of polymer are melted at about 280°C , pumped through a spinneret, cooled by air, and drawn to line up the chains. The filaments may be wound as smooth continuous filament, textured with heat into bulky yarn, or cut into staple and crimped for blending with cotton or wool. Acrylic does not melt cleanly, so it is dissolved in a solvent and spun wet (into a liquid) or dry (into warm air that evaporates the solvent).

The fabric science. Polyester's stiff, tightly packed chains have almost no water-loving groups. Its moisture regain is only about 0.4 percent, so it absorbs almost no water: it dries fast, does not shrink or stretch when wet, and holds its shape. The stiff chains also spring back, so polyester resists wrinkles, and because it softens with heat, pleats and creases can be heat-set permanently. It is strong, cheap, and resists sunlight better than nylon. Its weaknesses follow from the same chemistry: it feels clammy because it cannot absorb sweat (only wick it along fiber surfaces), it holds oily soil and body odor, builds static, pills, and melts at about 255°C , so a spark or a hot iron can melt it. Acrylic is soft, warm for its weight and colorfast, but pills readily and is heat-sensitive.

Blending. Polyester's great talent is partnership. A 65/35 polyester/cotton shirting combines polyester's strength and wrinkle resistance with cotton's comfort and absorbency; a 50/50 T-shirt shrinks less than cotton alone. Blending ratios are chosen by testing, the way you will test, not by fashion.

The studio lab. This is the unit's moisture-regain and drying-time lab. You will humidify and weigh five fibers (cotton, rayon, wool, nylon and polyester) to measure regain, then soak and weigh five fabrics to draw drying curves. Two properties, five fibers, one fair test.

PICTURE STUDY



*Setting a New Warp onto a Loom, Madison Silk Company, Paterson, Photographer for the Works Progress Administration's National Research Project, c. 1937 · Photograph · U.S. National Archives
Image: [Wikimedia Commons](#), public domain*

Paterson, New Jersey, called itself the Silk City. By the 1930s, when this photograph was made for a government study of American industry, its mills wove more and more rayon and other manufactured filament yarns alongside silk. Setting a new warp means bringing hundreds of fine filament ends from a beam into the loom, end by end, before a single pick can be woven.

Look closely

- Find the warp ends. How many can you count across a few inches, and how fine do they look?
- Find the worker's hands. What exactly is being done to each end?
- Look at the light reflecting on the yarns. Does it look like spun staple or smooth filament?
- Look at the loom's frame and the beam. Where does the warp come from?

Talk about it

1. Smooth filament yarns of polyester or nylon are slippery. What problems might that cause the weaver, compared with spun cotton?

2. Why would a mill that once wove silk switch to manufactured filaments?
3. How long might it take to tie or thread a warp of several thousand ends?

Safety first. Use the oven for drying samples only with a parent's permission, at or below 200 °F (93 °C), on parchment, with mitts; polyester and nylon can soften if overheated. Wipe up spills from the soaking bowls promptly.

STUDIO LAB

Five Fibers: Moisture Regain and Drying Time

Question: How do cotton, rayon, wool, nylon and polyester compare in moisture regain and drying time? You will measure both properties in a fair test and connect each result to the fiber's chemistry.

You will need

- About 10 g each of five fibers or yarns (cotton, rayon or viscose, wool, nylon, polyester); fabric scraps work if fiber is hard to find
- Five 4 × 4 in knit or woven swatches of the same five fibers, as close in weight as you can find
- The 0.1 g scale, a low oven, a baking sheet and parchment
- A clear plastic tub with lid, a bowl of warm water and a rack (from Lesson 2.1)
- A drying rack, clothespins, a timer and graph paper

Steps

1. **Hypothesis.** Rank the five fibers by regain and by drying time, and explain each guess with a chemistry reason.
2. **Regain.** Dry the five fiber samples on parchment at 200 °F for 45 minutes, cool them in sealed bags, and weigh each quickly.
3. Set the samples on the rack in the humid tub for 24 hours. Weigh each and calculate regain. (If you have no oven, measure gain from room air to humid air instead.)
4. **Drying.** Weigh each dry swatch. Soak all five for 5 minutes, lift them out, let them drip 30 seconds, and weigh.
5. Hang them side by side away from sun and drafts. Weigh each every 10 minutes until all are back within 0.2 g of their dry weight, or for 90 minutes.
6. Calculate water pick-up and the percent of water remaining at each time, and draw five drying curves on one graph.
7. **Conclude.** Did fibers with higher regain also take up more water and dry more slowly? Which result surprised you?
8. **Repeat round.** Run the drying test again with a fan blowing gently on all five. Which fibers gained most from moving air?

Tips

- Fabric structure matters for drying: a fluffy knit holds more water between its loops than a thin woven. Note your swatch types.
- Water pick-up (water held between fibers) and regain (water held inside fibers) are different things; this lab measures both.
- Polyester's regain is so low that your scale may barely detect it. That is a real result: record what you see.

Check your work

- ☐ I dried, humidified and weighed all fibers the same way and reported regain to one decimal.
- ☐ I graphed five drying curves on one set of axes.
- ☐ I explained each fiber's result with its chemistry (water-loving groups, crystallinity).

LAB NOTEBOOK

1. Draw a melt-spinning line: hopper, melter, pump, spinneret, cooling air, draw rolls, winder. Label what happens at each.
2. Draw the three spinning methods side by side (wet, dry, melt) and list two fibers made by each.
3. Paste your drying graph and write the five regains beside the legend.

KEY FORMULAS

$$\text{regain} = \frac{m_{\text{humid}} - m_{\text{dry}}}{m_{\text{dry}}} \times 100\%$$

$$\text{regain} = m_{\text{dry}} m_{\text{humid}} - m_{\text{dry}} \times 100\%$$

$$\text{drying rate} = \frac{\Delta m_{\text{water}}}{\Delta t}$$

$$\text{drying rate} = \Delta t \Delta m_{\text{water}}$$

$$\text{water pick-up} = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{dry}}} \times 100\%$$

$$\text{water pick-up} = m_{\text{dry}} m_{\text{wet}} - m_{\text{dry}} \times 100\%$$

From history. Most plastic drink bottles are made of the same polymer as polyester fiber, PET. Since the 1990s, mills have melted down used bottles and spun them into fleece and fiberfill, so the same molecule may be a bottle one year and a jacket lining the next.

WORKED EXAMPLES

Example 1. Five 10.0 g fiber samples, oven-dried, weigh after a day at room humidity: cotton 10.8 g, rayon 11.2 g, wool 11.4 g, nylon 10.4 g, polyester 10.04 g. Find each regain.

Show solution

1. Cotton $0.8/10.0 = 8\%$; rayon $1.2/10.0 = 12\%$; wool $1.4/10.0 = 14\%$; nylon $0.4/10.0 = 4\%$; polyester $0.04/10.0 = 0.4\%$.

Answer: Wool 14%, rayon 12%, cotton 8%, nylon 4%, polyester 0.4%: very close to the trade's standard values.

Example 2. A polyester knit swatch weighs 12.0 g dry and 21.6 g after soaking and dripping. A cotton knit of 12.0 g weighs 31.2 g. Find each water pick-up. After 30 minutes, the polyester weighs 13.2 g and the cotton 24.0 g. Find each average drying rate.

Show solution

1. Pick-up: polyester $\frac{9.6}{12.0} = 80\%$; cotton $\frac{19.2}{12.0} = 160\%$.
2. Polyester lost $21.6 - 13.2 = 8.4$ g; $8.4/30 = 0.28$ g/min.
3. Cotton lost $31.2 - 24.0 = 7.2$ g; $7.2/30 = 0.24$ g/min.

Answer: Polyester took up half as much water and was nearly dry (1.2 g left, 12.5% of its load) after 30 minutes, while cotton still held 12.0 g (62.5%).

Example 3. A 65/35 polyester/cotton shirt weighs 220 g dry. Using regains of 0.4% and 8.5%, how much water does it hold at room conditions? Compare with a 100% cotton shirt of the same dry weight.

Show solution

1. Polyester: $0.65 \times 220 = 143$ g; water $143 \times 0.004 = 0.6$ g.
2. Cotton: $0.35 \times 220 = 77$ g; water $77 \times 0.085 = 6.5$ g.
3. Blend total 7.1 g; all-cotton $220 \times 0.085 = 18.7$ g.

Answer: About 7 g for the blend against about 19 g for all cotton: the blend absorbs less, dries faster and feels less absorbent.

PRACTICE

1. Easy Who invented polyester fiber, where, and in what year?

Show answer

John Rex Whinfield and James Tennant Dickson, at the Calico Printers' Association in Manchester, 1941.

2. Easy Which spinning method is used for polyester? For acrylic?

Show answer

Polyester: melt spinning. Acrylic: wet or dry (solution) spinning.

3. Easy What is the difference between filament and staple?

Show answer

Filament is continuous; staple is cut into short lengths and crimped for spinning.

4. Medium A 20.0 g dry polyester sample weighs 20.08 g after conditioning. Find its regain.

Show answer

$$0.08/20.0 = 0.4\% \quad 0.08/20.0 = 0.4\%$$

5. Medium A swatch weighs 15 g dry and 33 g wet. Find its water pick-up.

Show answer

$$18/15 = 120\% \quad 18/15 = 120\%$$

6. Medium Why can pleats be heat-set permanently in polyester but not in cotton?

Show answer

Polyester softens with heat; set in a new shape and cooled, its chains lock there. Cotton does not soften; its creases are held only by hydrogen bonds that water undoes.

7. Medium Explain why polyester shirts can hold body odor.

Show answer

Polyester is oleophilic: it attracts and holds body oils, which bacteria break down into odors, and cool washes do not fully remove them.

8. Hard A 50/50 cotton/polyester T-shirt weighs 160 g dry. Find the water it holds at room conditions (cotton 8.5%, polyester 0.4%).

Show answer

$$80 \times 0.085 + 80 \times 0.004 = 6.8 + 0.32 \approx 7.1 \text{ g} \quad 80 \times 0.085 + 80 \times 0.004 = 6.8 + 0.32 \approx 7.1 \text{ g}$$

9. Hard A swatch loses 6.6 g of water in 20 minutes. Find its drying rate, and how long it would take to lose 10 g at that rate.

Show answer

$$0.33 \text{ g/min} \quad 0.33 \text{ g/min}; \quad 10/0.33 \approx 30 \text{ min} \quad 10/0.33 \approx 30 \text{ min (real drying slows near the end).}$$

10. Hard The repeat unit of PET is $\text{C}_{10}\text{H}_8\text{O}_4$. Find its molar mass.

Show answer

$$120.10 + 8.06 + 64.00 = 192.16 \text{ g/mol} \quad 120.10 + 8.06 + 64.00 = 192.16 \text{ g/mol}$$

11. Challenge Design a shirt for a hot, humid summer job outdoors. Choose cotton, polyester or a blend and defend the choice with regain, drying and odor data.

Show answer

A good answer weighs cotton's absorbency and comfort against its slow drying, and polyester's fast drying and wicking against clamminess and odor; a blend or a moisture-wicking polyester knit may be defended, or cotton for absorbency in shade. Credit for reasoning from data.

COMMON MISTAKES

- Saying polyester “doesn't breathe” as if it were plastic film. Woven or knit polyester lets air through its spaces; it simply cannot absorb water into the fiber.
- Ironing polyester on high. It softens and glazes at temperatures cotton handles easily.
- Calling every soft, wool-like sweater wool. Acrylic is made to look and feel like wool; read the label or burn-test.

Make it a game · Drip-Dry Derby. Each player picks a different fabric from the rag bag, soaks it, drips it for 30 seconds and hangs it on the line. Before starting the timer, everyone predicts the finishing order. Check by touch every five minutes; the first to feel completely dry wins the race, and the player who predicted the order best wins the derby.

3.4 SHIVERS'S SPANDEX AND THE SCIENCE OF STRETCH

OBJECTIVES

- Tell how Joseph Shivers and DuPont developed spandex in 1958 to replace rubber thread.
- Explain how segmented polyurethane, with soft and hard segments, stretches several times its length and recovers, and how core-spun yarns use it.
- Measure elongation, recovery and permanent growth of stretch fabrics and calculate each.

Warm-up. Find three stretchy things: a sock cuff, a pair of stretch jeans, a fitted knit shirt. Read their labels for spandex, elastane or Lycra. Stretch each and let go. Which springs back fastest, and which stays a little baggy?

WATCH

Basics of Polyurethane

BASF • 2:45

<https://www.youtube.com/watch?v=cW3tzRzTHKI>

WHEN TO WATCH

After “How they figured it out.” This short chemistry animation from a polyurethane maker shows how polyurethanes are built from two kinds of building blocks; spandex is a polyurethane whose blocks form the soft and hard segments of this lesson.

Note: No suitable spandex-fiber video met this course’s standards; this polyurethane primer explains the chemistry family, and the lesson text carries the fiber details.

BACKUP VIDEO

How Rubber Bands Are Made

Insider • 3:37

<https://www.youtube.com/watch?v=aEIAYBGRyYY>

For the story: watch natural rubber kneaded, vulcanized with sulfur and formed, the material spandex was invented to replace.

KEY TERMS

spandex

A synthetic elastic fiber made of at least 85% segmented polyurethane; called elastane in Europe. The name is an anagram of “expands.”

soft and hard segments

In spandex, long flexible soft segments that uncoil when stretched, linked by short rigid hard segments that hydrogen-bond into tie points and pull the chains back.

elongation

How much a fiber or fabric lengthens under a load, as a percent of its original length.

elastomer

A polymer that can stretch to several times its length and spring back, like rubber.

core-spun yarn

A yarn with a stretched spandex filament in the center wrapped by cotton or other staple fibers, so the fabric feels like cotton but stretches.

growth (permanent set)

The part of a stretch that does not recover; a baggy knee in stretch pants is growth.

CORE IDEAS

The story. For a century, anything that had to stretch and snap back, a waistband, a sock top, a surgical stocking, used threads of natural rubber. Rubber was heavy, broke down from body oils, sweat and sunlight, and could not be dyed well. After World War II, DuPont asked its chemists for a synthetic replacement. Joseph Shivers, a chemist who had joined DuPont in 1946, worked on the problem for years, and in 1958 he and his team found the answer, which DuPont first called Fiber K. It was sold under the trademark Lycra from the early 1960s, and its generic name became spandex.

How they figured it out. Shivers knew rubber's secret: long, coiled, flexible chains held together at a few points, so they can uncoil when pulled and snap back when released. He built that structure on purpose with polyurethane chemistry, alternating long, floppy *soft segments* with short, stiff *hard segments*. The hard segments cluster together and hydrogen-bond into tiny rigid domains, acting like knots tying the soft chains into a stretchy net. The polymer is dissolved and dry-spun into fine filaments, often fused together in bundles.

The fabric science. Pull a spandex fiber and its soft segments uncoil; it can stretch to five times its length or more before breaking. Let go, and the coiled segments, anchored by the hard domains, pull it back nearly to its original length. Spandex is lighter, stronger and more durable than rubber, resists body oils and sweat, and takes dye. So little is needed that most fabrics contain only 2 to 10 percent: a 98/2 cotton/spandex denim gains comfortable stretch, and a 95/5 cotton/spandex knit keeps its shape. Spandex has weaknesses too: chlorine bleach and chlorinated water break it down, high heat in a dryer or under an iron weakens it, and it ages over years, which is why old waistbands lose their snap.

Stretch in fabrics. A fabric's stretch comes from three places: the fiber (spandex), the yarn (texturing, crimp and core-spinning) and the fabric structure (knits stretch far more than wovens, and the bias of a woven stretches more than its grain). Recovery is what separates good stretch from bad: a fabric that stretches 30 percent but grows 5 percent permanently will bag at the knees. Clothing engineers test both, often at a set load and time.

The studio lab. You will hang a fixed weight on fabric strips, cotton knit, cotton/spandex knit, stretch denim, plain denim and a rib knit, and measure how far each stretches, how much it recovers after one minute and after thirty, and how much permanent growth remains.

PICTURE STUDY



On a Rubber Plantation, Sumatra, C. J. Kleingrothe (photographic studio), Medan, c. 1920 · Photograph · KITLV collection, Leiden University Libraries; image from Wikimedia Commons (public domain)
Image: [Wikimedia Commons](#), public domain

Before spandex, every elastic thread in the world began with trees like these. Workers cut thin grooves in the bark of each rubber tree each morning and collected the milky latex in cups, then carried it in buckets to be dried and processed into rubber. Some rubber was cut into fine threads and wrapped with cotton for elastic garters, waistbands and braces.

Look closely

- Find the worker with the shoulder pole and buckets. What might he be carrying, and how far might he walk in a morning?
- Look at the trees. How tall are they, and how closely are they planted?
- Find the two men in white at the right. What might they be inspecting?
- Look at the trunks. Where on a trunk would a tapper cut, and why would the cut slope?

Talk about it

1. Rubber elastic broke down from sweat, body oil and sunlight. How does this picture help explain why DuPont wanted a fiber made in a factory?

2. Natural rubber and spandex both stretch because of coiled chains tied at a few points. What did Shivers copy from the tree?
3. What are the advantages of a stretch fiber that does not depend on one crop in one part of the world?

Safety first. Hang weights over a soft surface and keep feet clear. Do not stretch strips toward your face; a slipping clip can snap back. Count pins and needles at the end of the session.

STUDIO LAB

Stretch and Snap-Back: Elongation and Recovery

Question: How much do stretch fabrics elongate under a fixed load, and how well do they recover? You will compare fabrics with and without spandex, knit and woven, and measure growth after one minute and after thirty.

You will need

- Strips 2 × 8 in of: cotton jersey (a 100% cotton T-shirt), cotton/spandex jersey (a stretch T-shirt or knit), stretch denim, plain denim, and a rib knit (a sock cuff or ribbed top)
- The dowel rig, two binder clips per strip, a 1 kg weight (a filled water bottle in a bag), a ruler in mm and a fabric marker
- A timer

Steps

1. **Hypothesis.** Rank the five fabrics by elongation and by recovery.
2. Cut each strip with the stretch direction along its length (crosswise for knits, the direction that stretches for denim). Mark two lines exactly 10.0 cm apart in the middle.
3. Clip the top of the strip to the dowel and the 1 kg weight to the bottom. After 1 minute under load, measure the marked length.
4. Remove the weight and lay the strip flat. Measure the marked length after 1 minute and again after 30 minutes.
5. Repeat for all five fabrics, using the same weight and times.
6. Calculate elongation, recovery and growth at 1 minute and 30 minutes. Make a table and a bar graph of growth.
7. **Conclude.** Which fabric stretched most? Which recovered best? Did spandex matter more than knit structure, or less?
8. **Repeat round.** Load the cotton/spandex strip ten times in a row for 1 minute each, then measure growth. Does repeated stretching (like a day of wear) increase growth?

Tips

- Measure quickly but carefully; knits begin recovering the moment the load comes off.
- If a strip curls (jersey edges roll), measure it flat under a ruler without stretching.
- Test the woven denim along its weft (crosswise): that is where stretch denim's spandex usually runs.

Check your work

- ☐ I used the same load, marked length and timing for every fabric.
- ☐ I calculated elongation, recovery and growth correctly with units.
- ☐ I identified which source of stretch (fiber, yarn or structure) best explains each result.

LAB NOTEBOOK

1. Draw a spandex chain as springs (soft segments) joined by small blocks (hard segments) clustered together. Draw it again stretched.
2. Draw a core-spun yarn in cutaway: spandex core, staple wrapping.
3. Tape in the five test strips with their elongation and growth written beside each.

KEY FORMULAS

$$\text{elongation} = \frac{L_{\text{loaded}} - L_0}{L_0} \times 100\%$$

$$\text{elongation} = L_0 L_{\text{loaded}} - L_0 \times 100\%$$

$$\text{recovery} = \frac{L_{\text{loaded}} - L_{\text{after}}}{L_{\text{loaded}} - L_0} \times 100\%$$

$$\text{recovery} = L_{\text{loaded}} - L_0 L_{\text{loaded}} - L_{\text{after}} \times 100\%$$

$$\text{growth} = \frac{L_{\text{after}} - L_0}{L_0} \times 100\%$$

$$\text{growth} = L_0 L_{\text{after}} - L_0 \times 100\%$$

From history. The trademark Lycra became so well known that people used it as a common word, like zipper. The generic name spandex was chosen in the United States by rearranging the letters of “expands.”

WORKED EXAMPLES

Example 1. A 10.0 cm marked length of cotton/spandex knit stretches to 14.2 cm under the load. One minute after release it measures 10.4 cm. Find the elongation, recovery and growth.

Show solution

1. Elongation: $\frac{14.2 - 10.0}{10.0} \times 100\% = 42\%$

2. Recovery: $\frac{14.2 - 10.4}{14.2 - 10.0} \times 100\% = \frac{3.8}{4.2} \times 100\% = 90.5\%$

3. Growth: $\frac{10.4 - 10.0}{10.0} \times 100\% = 4\%$

Answer: 42% elongation, about 90% recovery and 4% growth after one minute.

Example 2. The same knit without spandex stretches from 10.0 to 13.5 cm and returns only to 11.3 cm. Find its recovery and growth, and compare.

Show solution

1. Recovery: $\frac{13.5 - 11.3}{13.5 - 10.0} \times 100\% = \frac{2.2}{3.5} \times 100\% = 62.9\%$

2. Growth: $\frac{11.3 - 10.0}{10.0} \times 100\% = 13\%$

Answer: About 63% recovery and 13% growth against 90% and 4%: a few percent spandex makes the difference between a knit that bags and one that springs back.

Example 3. A pair of stretch jeans weighs 620 g and is 98% cotton, 2% spandex. How many grams of spandex does it contain? If spandex costs ten times as much per gram as cotton, about what share of the fiber cost is spandex?

Show solution

1. Spandex: $620 \times 0.02 = 12.4$ g; cotton 607.6 g

2. Cost units: cotton $607.6 \times 1 = 607.6$, spandex $12.4 \times 10 = 124$

3. Share: $\frac{124}{607.6 + 124} \times 100\% = 17\%$

Answer: About 12 g of spandex, roughly 17% of the fiber cost on these assumptions: a small amount doing a big job.

PRACTICE

1. **Easy** Who led the development of spandex, and in what year?
Show answer
Joseph Shivers, at DuPont, 1958.
2. **Easy** What natural material did spandex replace, and name two of that material's weaknesses.
Show answer
Rubber thread; it broke down from body oils, sweat and sunlight, was heavy and dyed poorly.
3. **Easy** What is a core-spun yarn?
Show answer
A spandex filament in the center wrapped with staple fibers such as cotton.
4. **Medium** A 20 cm strip stretches to 26 cm. Find the elongation.
Show answer
 $6/20 = 30\%$
5. **Medium** A strip goes 10.0 → 13.0 cm loaded and returns to 10.3 cm. Find recovery and growth.
Show answer
Recovery $2.7/3.0 = 90\%$; growth $3/3.0 = 100\%$.
6. **Medium** Describe what soft and hard segments each do in spandex.
Show answer
Soft segments uncoil to give stretch; hard segments cluster and hydrogen-bond into tie points that pull the chains back.
7. **Medium** Name three sources of stretch in a fabric besides spandex.
Show answer
Knit structure, textured or crimped yarns, and cutting on the bias (also crimp in woven yarns).
8. **Hard** Why should stretch clothing not be washed with chlorine bleach or dried on high heat?
Show answer
Chlorine and high heat break down the polyurethane segments, so spandex loses its recovery and can snap.
9. **Hard** A 95/5 cotton/spandex knit shirt weighs 180 g. How many grams of each fiber does it contain?
Show answer
Cotton 171 g; spandex 9 g.
10. **Hard** After 30 minutes of rest, a strip that grew from 10.0 to 10.6 cm has shrunk back to 10.2 cm. What does that tell you about recovery over time?
Show answer
Some recovery is slow (delayed): growth fell from 6% to 2%, so a garment may look better after resting between wearings.
11. **Challenge** A family wants work pants that move with a farmer, last for years and survive hot washes. Recommend a fabric and fiber content, and explain the trade-offs of adding spandex.
Show answer
For example: cotton or cotton/polyester twill with 2–3% spandex for movement, or a mechanical-stretch twill with no spandex for maximum heat tolerance. Spandex adds comfort but can be weakened by hot washes and dryers and ages over years; less spandex and gentler drying extend life.

COMMON MISTAKES

- Thinking stretch fabrics are mostly spandex. Most contain 2–10%; the rest is ordinary fiber.
- Measuring recovery only once. Recovery continues for minutes after release; record the time.
- Drying stretch clothes on high heat. Heat and chlorine shorten spandex's life.

Make it a game · Snap-Back Showdown. Players each choose a stretchy item from the house (a sock, a hair tie, a waistband, a knit glove). Mark 10 cm with chalk, stretch to the same 15 cm against a ruler for 30 seconds, release, and measure after one minute. Smallest growth wins. Then everyone guesses which items contain spandex before checking labels.

3.5 MICROFIBERS, BLENDS AND THE FAIR VERDICT

OBJECTIVES

- Explain what a microfiber is, how splittable fibers are made, and why fine fibers clean, insulate and drape differently.
- Calculate denier per filament and filament diameter, and fiber masses in blends.
- Identify synthetic fibers by burn test safely and write a fair, data-based verdict on natural and manufactured fibers.

Warm-up. Wipe a smudge from a window or eyeglasses with a cotton towel, then with a microfiber cloth. Which works better? Look at the cloth's edge under your magnifier and describe what you see.

WATCH

Fabric Burn Test

[Sawyer Brook Distinctive Fabrics](#) · 10:25

<https://www.youtube.com/watch?v=-SriB05FLU4>

WHEN TO WATCH

Before the lab, with your parent. Watch how each synthetic snippit behaves as it nears the flame, and look closely at the bead it leaves.

BACKUP VIDEO

What Is Microfiber? - Dane Explains

[The Rag Company](#) · 2:47

<https://www.youtube.com/watch?v=IDuzSoiJt7o>

A short explanation of what a microfiber is and why it cleans so well.

KEY TERMS

microfiber

A fiber finer than 1 denier per filament, thinner than the finest silk.

splittable fiber

A filament spun from two polymers (often polyester and nylon) arranged in wedges that separate after weaving or knitting into many ultra-fine fibers.

fiber content label

The label required by U.S. law listing each fiber by generic name and percent by weight, in order of predominance.

denier per filament (dpf)

The denier of a yarn divided by the number of filaments in it; a measure of fiber fineness.

intimate blend

A yarn in which two or more fibers are mixed before spinning, so every inch contains both.

trade-off

Gaining one property at the cost of another; every fiber choice involves them.

CORE IDEAS

The story. In 1970 the Japanese chemist Miyoshi Okamoto, at the Toray company, developed a way to spin extremely fine fibers and needle them into a nonwoven fabric with the soft nap of suede. Sold as Ultrasuede in the United States, it washed in a machine, did not stain with water spots, and wore for years. It introduced the world to microfibers. By the 1990s microfiber polyester and nylon were everywhere: soft fleeces, light raincoats, peach-skin shirts and the cleaning cloths in nearly every kitchen.

How they figured it out. Spinning a filament finer than 1 denier is hard; it breaks easily. One clever solution spins a thicker filament of two polymers, polyester and nylon, arranged like the wedges of an orange. After the cloth is made, a chemical or mechanical treatment splits the wedges apart, turning one filament into eight or sixteen ultra-fine ones with sharp edges. Those edges and the tiny spaces between fibers grab grease and dust and wick water by capillary action, which is why a microfiber cloth cleans glass without soap.

The fabric science. Fineness changes everything. A thinner fiber bends more easily (softer hand, better drape), packs into denser fabric (wind and water resistance with breathability), and has much more surface area per gram (better wicking and cleaning, and more surface to soil). Halving the diameter roughly quadruples the number of fibers per gram. Blends play the same game with fiber types: polyester's strength and wrinkle resistance with cotton's absorbency; wool's warmth with nylon's toughness; cotton's comfort with a little spandex for stretch. Every choice is a trade-off, and a good textile scientist names the trade-offs instead of calling one fiber good and another bad.

The fair verdict. Natural fibers are not saints and synthetics are not villains. Cotton is comfortable and absorbent but wrinkles, shrinks and dries slowly. Wool is warm even when damp and resilient but can felt and costs more. Silk is beautiful and strong but delicate in care. Rayon drapes and absorbs but is weak wet. Nylon is the toughest but yellows in sun and feels clammy. Polyester is strong, quick-drying, wrinkle-resistant and cheap but holds odors and melts. Spandex gives stretch but dislikes heat and chlorine. All of them come from God's creation, whether grown in a field or built from carbon by chemists; all require work, energy and care. Choose by the job, care for what you choose, and wear it out.

The studio lab. With a parent beside you, you will burn-test nylon, polyester, acrylic and acetate or spandex blends, adding them to your identification kit. Then you will face the unit challenge: five unknown fabrics from all three families, identified with burn, feel, water-drop and magnifier evidence.

PICTURE STUDY



The Syndics of the Drapers' Guild (De Staalmeesters), Rembrandt van Rijn, 1662 · Oil on canvas · Rijksmuseum, Amsterdam

Image: [Wikimedia Commons](#), public domain

These five men in black were the sampling officials of Amsterdam's drapers' guild, chosen each year to judge the quality of dyed cloth against official samples and to fix its grade. Rembrandt painted them at their table as if someone had just walked in, which is how a good inspector should feel all the time: ready to give a fair verdict on the cloth in front of him.

Look closely

- Find the large book on the table. What would a cloth inspector record in it?
- Look at the Persian carpet covering the table. What can you tell about its colors and pattern?
- Look at the men's clothing: black wool, white linen collars. Which fibers from this course can you identify by eye?
- Find the man without a hat standing in back. Who might he be?

Talk about it

1. These officials judged cloth by comparing it with standard samples. How is that like your identification kit and your lab tests?
2. What makes a verdict fair? List three habits these inspectors would need.
3. If you were a sampling official judging a polyester and a cotton shirt, what tests would you run before ruling?

Safety first. Burn tests of synthetics are done **only with a parent beside you:** a ½-inch snippet in tweezers or hemostats over a metal pan or sink, water at hand, hair tied back, sleeves pushed up, and the snippet held well away from your face, because melting synthetics drip and burning drops stick to skin. Work by an open window or under a range hood, since synthetic smoke is irritating, and never burn more than a snippet.

STUDIO LAB

The Unknowns Challenge: All Three Families

Question: Can you identify any common fiber, plant, animal or manufactured, using all the evidence you have learned to gather? You will burn-test the manufactured fibers to complete your kit, then identify five unknowns a parent prepares.

You will need

- Known snippets: nylon, polyester, acrylic, and acetate or a spandex blend if available
- Five unknown fabrics, labeled 1–5 by a parent, drawn from all three families (blends allowed)
- The burn-test setup (tweezers, metal pan, water, candle), the 10× magnifier, an eyedropper and water
- All your identification cards from Units 1–3

Steps

1. **Set up** with your parent by an open window: metal pan, candle, water, hair tied back.
2. **Hypothesis.** Predict how nylon, polyester and acrylic will each behave approaching, in and out of the flame.
3. Burn-test each known synthetic as in Lesson 1.5. Record approach (shrinks? melts?), flame, removal, smell and residue. Let beads cool fully before touching.
4. Make identification cards for each synthetic.
5. **Unknowns.** For each unknown, first gather non-burn evidence: feel, crumple test, water-drop test, magnifier view. Write a first guess.
6. Then burn-test a snippet of each unknown and update your identification. For any blend, separate warp and weft yarns and test them separately.
7. Write each final identification with the evidence that decided it.
8. Check your answers with your parent's key. For each miss, write which test misled you and how you would catch it next time.
9. **Verdict.** Using your unit data (wet strength, abrasion, regain, drying, stretch), write a one-page fair verdict comparing five fibers of your choice.

Tips

- Acetate smells sharp and vinegary and leaves a hard, brittle bead; acrylic burns with a sputtering flame and leaves a hard, irregular black bead.
- Nylon's smell is often described as celery-like; polyester's as sweetish, with black smoke.
- When unsure, test three snippets. Consistent behavior is evidence; one odd snippet is noise.

Check your work

- ☐ I burn-tested synthetics only with my parent beside me and followed every safety step.
- ☐ I used at least three kinds of evidence for each unknown and explained my reasoning.
- ☐ My verdict uses my own data and names strengths and weaknesses of every fiber fairly.

LAB NOTEBOOK

1. Draw a splittable filament in cross-section (orange-wedge pattern) before and after splitting.
2. Complete a master burn chart with every fiber from Units 1–3 in one table.
3. Write your one-page fair verdict and staple it into the notebook.

KEY FORMULAS

$$\text{dpf} = \frac{\text{yarn denier}}{\text{number of filaments}}$$

dpf = number of filamentsyarn denier

$$d (\mu\text{m}) \approx 11.89 \sqrt{\frac{\text{dpf}}{\rho}} \quad (\rho \text{ in g/cm}^3)$$

$$d (\mu\text{m}) \approx 11.89 \sqrt{\rho \text{ dpf}}$$

$$\sqrt{\rho \text{ dpf}}$$

(ρ in g/cm³)

From history. The U.S. Textile Fiber Products Identification Act, passed in 1958 and in force from 1960, requires most clothing and household textiles to carry a label naming each fiber by its generic name (such as polyester or rayon, not a trademark) and its percentage by weight. Unit 6 looks at that law and the care-label rule that followed.

WORKED EXAMPLES

Example 1. A 150-denier polyester yarn has 288 filaments. Find the denier per filament. Is it a microfiber?

Show solution

$$1. \text{ dpf} = \frac{150}{288} = 0.52 \text{ dpf} = 288150 = 0.52.$$

2. Below 1 dpf, so yes.

Answer: 0.52 dpf: a microfiber yarn.

Example 2. Find the diameter of a 1.0 dpf polyester filament ($\rho = 1.38 \text{ g/cm}^3$) and a 0.25 dpf filament. Compare with 18 μm merino.

Show solution

1. 1.0 dpf:

$$11.89 \sqrt{\frac{1.0}{1.38}} = 11.89 \times 0.851 = 10.1 \mu\text{m} \quad 11.89 \sqrt{1.381.0}$$

2. 0.25 dpf:

$$11.89 \sqrt{\frac{0.25}{1.38}} = 11.89 \times 0.426 = 5.1 \mu\text{m} \quad 11.89 \sqrt{1.380.25}$$

Answer: About 10 μm and 5 μm : one-half to one-quarter the width of fine merino. A quarter of the denier gives half the diameter.

Example 3. A splittable filament of 2.4 denier splits into 16 equal wedges. Find the dpf after splitting, and how many fibers 1 g of yarn contains per 9,000 m compared with before.

Show solution

$$1. \text{ After splitting: } \frac{2.4}{16} = 0.15 \text{ dpf} \quad 162.4 = 0.15 \text{ dpf.}$$

2. Same mass, same length, 16 times as many fibers: each original filament becomes 16.

Answer: 0.15 dpf, sixteen times as many fibers, with far more surface for wicking and cleaning.

PRACTICE

1. **Easy** What makes a fiber a microfiber?

Show answer

It is finer than 1 denier per filament.

2. **Easy** Who developed Ultrasuede, at which company, and in what year?

Show answer

Miyoshi Okamoto, Toray, 1970.

3. **Easy** Describe the burn behavior of polyester.

Show answer

Shrinks from the flame, melts and drips, burns with dark smoke and a sweetish chemical smell, leaves a hard dark bead.

4. **Medium** A 70-denier nylon yarn has 68 filaments. Find its dpf.

Show answer

$70/68 \approx 1.0370/68 \approx 1.03$ dpf (just above microfiber).

5. **Medium** Find the diameter of a 4 dpf nylon filament ($\rho = 1.14 \text{ g/cm}^3$).

Show answer

$11.89 \sqrt{4/1.14} \approx 22.3 \mu\text{m}$

$\sqrt{4/1.14}$

$\approx 22.3 \mu\text{m}$

6. **Medium** Why do microfiber cloths clean glass without soap?

Show answer

Ultra-fine, often wedge-edged fibers and the tiny capillary spaces between them pick up and hold oil and dust by surface contact and wicking.

7. **Medium** A 65/35 polyester/cotton sheet set weighs 1.4 kg. Find each fiber's mass.

Show answer

Polyester 0.91 kg; cotton 0.49 kg.

8. **Hard** If dpf is cut to one-ninth, by what factor does the filament diameter change, and the number of filaments per gram?

Show answer

Diameter becomes one-third; there are nine times as many filaments per gram.

9. **Hard** An unknown melts and drips, smells like celery, and leaves a hard gray bead. What is it likely to be?

Show answer

Nylon.

10. **Hard** Write the fiber-content label for a 300 g sweater containing 165 g acrylic, 90 g wool and 45 g nylon.

Show answer

55% acrylic, 30% wool, 15% nylon (listed in order of predominance by weight).

11. **Challenge** Write a fair, four-sentence verdict on polyester that a cotton farmer and a polyester chemist could both accept as accurate.

Show answer

A good answer credits polyester's strength, quick drying, wrinkle resistance, shape retention and low cost; states its real weaknesses (low absorbency, odor and oil holding, static, pilling, melting); notes where it excels (outerwear, blends, quick-dry gear) and where cotton serves better (towels, hot-weather comfort); and avoids calling either fiber good or bad in itself.

COMMON MISTAKES

- Holding a melting synthetic snippet over your other hand. Molten drops stick and burn; always work over the pan.
- Calling a blend by its first fiber only. A 50/50 blend shows both families' behavior.

- Judging fibers by reputation instead of data. Your lab results are better evidence than slogans.

Make it a game · Fiber Courtroom. One player is the judge, holding a mystery fabric; the others are lawyers. Each lawyer may ask the judge for one test result (feel, water drop, crumple, magnifier view, or a burn result the judge reads from the parent's key) and then must name the fiber. A correct verdict after one test earns three points, after two tests two, after three tests one. Rotate judges.

UNIT 3 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (6 pts)
Distinguish regenerated fibers from synthetic fibers and give two examples of each.
2. (7 pts)
Outline the viscose process from wood pulp to filament.
3. (7 pts)
Rayon breaks at 380 g dry and 205 g wet. Find its wet-strength retention and explain the cause of the loss.
4. (7 pts)
Find the molar mass of cellulose chains with DP 400 and DP 9,000.
5. (7 pts)
Tell the story of nylon's discovery in three or four sentences, including cold drawing and the first products.
6. (7 pts)
A 20-denier filament is drawn 4 times. Find the new denier, and explain what drawing does to the chains.
7. (6 pts)
Name the three spinning methods and one fiber made by each.
8. (7 pts)
A 10.0 g dry sample weighs 10.05 g after conditioning. Find its regain and name the fiber it most likely is.
9. (7 pts)
A swatch weighs 14.0 g dry and 26.6 g wet; after 20 minutes it weighs 18.2 g. Find its water pick-up, the percent of water remaining, and the average drying rate.
10. (7 pts)
A stretch knit's 10.0 cm mark stretches to 13.6 cm and recovers to 10.3 cm. Find the elongation, recovery and growth.
11. (6 pts)
Explain how soft and hard segments give spandex its stretch and recovery, and name two things that damage it.
12. (7 pts)
A 220-denier yarn has 440 filaments. Find its dpf and say whether it is a microfiber. Find the diameter of one filament if $\rho = 1.38 \text{ g/cm}^3$.
13. (6 pts)
A 400 g jacket is 80% polyester, 20% cotton. Find each fiber's mass and the water it holds at room conditions (0.4% and 8.5% regain).
14. (6 pts)
Describe the burn behavior that distinguishes nylon, polyester and acrylic from rayon.
15. (7 pts)
Short essay (5–7 sentences): Write a fair verdict on natural versus manufactured fibers, using at least three measured results from this unit's labs.

UNIT PROJECT: A FIBER-TESTING REPORT: FIVE FIBERS, FIVE TESTS

Write a formal fiber-testing report, the kind a textile lab sends a customer, comparing at least five fibers (both natural and manufactured) on at least four properties you measured this unit and earlier: wet strength, abrasion, moisture regain, drying time, stretch and recovery, or burn behavior.

The report has a title page, a short introduction stating the question, a methods section, data tables and graphs with units, a results discussion, and a one-page fair verdict recommending one fiber or blend for each of three real uses (for example, a towel, a hiking shirt, a pair of work pants). Add the manufactured-fiber cards to your identification kit.

LOOK FOR	WHAT IT MEANS
Method and fairness	Each test changed one variable, controlled the others, and is described clearly enough to repeat.
Data and math	Tables and graphs are complete, labeled with units, and the calculations are correct.
Reasoning	Results are explained with the chemistry of each fiber (chains, crystallinity, water-loving groups, segments).
Fair verdict	Recommendations name real strengths and weaknesses of every fiber and fit the stated uses.
Safety and honesty	Burn tests were done with a parent beside you; surprises and failed trials are reported.

ANSWER KEY

1. Regenerated: a natural polymer (cellulose) dissolved and re-formed, e.g., rayon, lyocell (also modal, acetate). Synthetic: polymers built from small molecules, e.g., nylon, polyester (also acrylic, spandex).
2. Pulp steeped in NaOH (alkali cellulose), crumbled and aged, reacted with carbon disulfide (cellulose xanthate), dissolved in dilute NaOH (viscose), ripened, extruded through a spinneret into an acid bath that regenerates cellulose filaments, then washed, cut or wound.
3. $205/380 \approx 54\%$ $205/380 \approx 54\%$. Short, loosely packed chains let water pry them apart so they slide.
4. 64,800 g/mol 64,800 g/mol and 1,458,000 g/mol 1,458,000 g/mol.
5. DuPont hired Wallace Carothers in 1928 for pure polymer research. Julian Hill discovered in 1930 that pulling and stretching a polymer thread (cold drawing) made it much stronger. On February 28, 1935, Gerard Berchet in Carothers's group made nylon 6,6. Toothbrush bristles came in 1938 and stockings went on sale in May 1940; in the war nylon went to parachutes and ropes.
6. 5 denier. Drawing pulls tangled chains parallel so they crystallize and share load.
7. Wet: rayon (or acrylic). Dry: spandex or acetate (or acrylic). Melt: nylon or polyester.
8. 0.5%; polyester.
9. Pick-up $12.6/14.0 = 90\%$ $12.6/14.0 = 90\%$; remaining $4.2/12.6 = 33\%$ $4.2/12.6 = 33\%$; rate $8.4/20 = 0.42 \text{ g/min}$ $8.4/20 = 0.42 \text{ g/min}$.
10. 36%; $3.3/3.6 \approx 91.7\%$ $3.3/3.6 \approx 91.7\%$; 3%.
11. Soft segments uncoil under load; hard segments cluster into hydrogen-bonded tie points that pull the chains back. Chlorine and high heat damage it.
12. 0.5 dpf, a microfiber; $11.89\sqrt{0.5/1.38} \approx 7.2 \mu\text{m}$ $11.89 \cdot 0.5/1.38$
 $\sqrt{}$
 $\approx 7.2 \mu\text{m}$.
13. Polyester 320 g (1.3 g water); cotton 80 g (6.8 g water); about 8.1 g total.
14. Nylon, polyester and acrylic shrink from the flame, melt and drip, and leave hard beads with chemical smells; rayon ignites quickly, burns like paper with an afterglow and leaves soft gray ash.
15. A strong essay cites real data (e.g., rayon's ~55% wet strength, nylon's high abrasion score, polyester's ~0.4% regain and fast drying, spandex blends' recovery), names strengths and weaknesses of both natural and manufactured fibers, and concludes that the right fiber depends on the job and that care and stewardship matter for all.

YARNS

Fibers become useful only when they are twisted into yarn. For thousands of years that was done with a stick and a whorl, the drop spindle, and every thread of every garment passed through a spinner's fingers. Then came the spinning wheel, and in the eighteenth century the spinning jenny, the water frame and the mule, which moved spinning from the cottage to the mill and began the industrial age. This unit tells that story honestly, from Proverbs 31's distaff to the mills of Arkwright, Slater and Lowell and the children Lewis Hine photographed at the spinning frames.

Then it measures. Twist is what holds a yarn together, and there is a best amount of it, which you will find in the twist-and-strength lab. You will count turns per inch, work in S and Z, ply singles into balanced yarn, and learn the count systems the trade uses (tex, denier, cotton count and yarn weight) well enough to convert any label. The unit ends with sewing thread: cotton, polyester and core-spun, and why the thread you choose matters as much as the fabric.

PREREQUISITES

- Units 1–3: staple length, filament and staple, denier
- Comfortable with ratios, unit conversions and the tangent of an angle (a calculator is fine)
- A drop spindle (or a homemade one: a ¼-inch dowel and a CD or wooden toy wheel) and a few ounces of wool roving

MASTERY CHECKLIST

- ☐ I can spin a usable singles yarn on a drop spindle and measure its twist in turns per inch.
- ☐ I can explain how twist holds staple fibers together, why too little or too much twist weakens yarn, and what S and Z twist and a balanced ply are.
- ☐ I can tell the history of Hargreaves, Arkwright, Crompton, Slater and the Lowell mills accurately and honestly, including child labor and how laws changed.
- ☐ I can convert between tex, denier, cotton count, metric count and yards per pound.
- ☐ I can choose sewing thread by fiber, construction and size for a fabric and a job.
- ☐ I can run a fair twist-and-strength test and graph the result.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Craft Yarn Council: Standard Yarn Weight System:** Free. The chart of yarn weight classes 0–7 with typical gauges and needle and hook sizes; Lesson 4.4 uses it.
- **A drop spindle and 4 oz of wool roving:** A simple top-whorl or bottom-whorl spindle costs a few dollars at fiber shops and festivals; a dowel pushed through a CD or wooden wheel works just as well.
- **A niddy-noddy or two chair backs:** For winding skeins of known length. A 2-yard niddy-noddy is a simple wooden reel; two chairs set 1 yard apart do the same job.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

4.1 The Spindle and the Wheel	3 sessions of 50 minutes
4.2 Hargreaves, Arkwright and Crompton	3 sessions of 50 minutes
4.3 Slater, Lowell and the Mill	3 sessions of 50 minutes
4.4 Yarn Count: Denier, Tex and Cotton Count	3 sessions of 50 minutes
4.5 Ply, Novelty Yarns and Sewing Thread	3 sessions of 50 minutes

4.1 THE SPINDLE AND THE WHEEL

OBJECTIVES

- Describe the drop spindle, the great wheel and the flyer wheel and how each adds twist and winds on yarn.
- Explain how twist holds staple fibers together and define S and Z twist and turns per inch.
- Spin a singles yarn, measure its twist and calculate its twist angle.

Warm-up. Pull a pinch of fibers from a cotton ball or a tuft of wool roving and try to make it hold a weight (a clothespin). Then twist the same pinch between your fingers as you draw it out and try again. Write down what changed.

WATCH

Spinning on a Drop Spindle

Schacht Spindle · 12:26

<https://www.youtube.com/watch?v=mae2CAkrZDo>

WHEN TO WATCH

Watch once through, then again with your spindle and roving in hand, pausing after each step: park, draft, release the twist, wind on.

BACKUP VIDEO

What is a spinning wheel and how does it work?

NC Museum of History · 2:18

<https://www.youtube.com/watch?v=AoGuNPdIbIs>

A museum educator shows how a spinning wheel twists and winds at the same time.

KEY TERMS

drop spindle

A shaft with a weighted whorl that is spun by hand and hangs from the yarn, adding twist as it turns.

drafting

Drawing fibers out of the mass to the thickness wanted before the twist runs into them.

turns per inch (TPI)

The number of full twists in one inch of yarn; in metric, turns per meter.

distaff

A stick or staff that holds unspun fiber, especially flax, ready for the spinner.

S and Z twist

The direction of twist: in S twist the slant of the fibers follows the middle of the letter S; in Z twist, the middle of a Z.

flyer

The U-shaped arm on a spinning wheel that turns around the bobbin, adding twist and winding yarn on at the same time.

CORE IDEAS

The story. Spinning is one of the oldest crafts. Spindle whorls of stone and clay turn up in ancient sites everywhere, and the capable woman of Proverbs “layeth her hands to the spindle, and her hands hold the distaff.” For most of history, women and girls spun whenever their hands were free, walking, watching sheep, talking with neighbors, because a household needed enormous amounts of yarn: by one common estimate, several spinners to keep a single weaver busy. The word spinster once simply meant a woman who spun.

How they figured it out. The drop spindle is a lever and a flywheel. Flick it, and the weighted whorl keeps it turning while gravity pulls the yarn taut; the spinner drafts fibers from the distaff or roving and lets the twist run up into them. When the spindle nears the floor, she winds the new yarn onto the shaft. The great wheel, which reached Europe by the 1200s, spins a spindle with a big drive wheel, many turns per crank, but the spinner must stop to wind on. The flyer wheel, developed by the 1500s and later given a foot treadle, spins and winds at once: the flyer turns a little faster or slower than the bobbin, so yarn is twisted and wound on continuously while both hands draft. It is the wheel in Lesson 4.1's backup video and in colonial homes.

The fabric science. Short staple fibers hold together only by friction. Twist wraps them into helices around the yarn's axis; when the yarn is pulled, the helices tighten and squeeze each fiber against its neighbors, so friction grips them and they cannot slide apart. More twist means more grip, up to a point. The twist angle θ , the angle the surface fibers make with the yarn's axis, depends on the yarn's diameter d and its twist T : $\tan \theta = \pi d T$. A thick yarn needs fewer turns per inch than a thin one to reach the same angle and the same grip. Twist direction is named S or Z by the slant of the surface fibers. Most machine-spun singles are Z-twisted, and most sewing threads end with an S ply, a convention that matters when thread meets the sewing machine's hook.

Look closely. Under the magnifier, a well-spun singles shows fibers lying at a steady slant. Thick spots have fewer turns (twist runs to thin places first), which is why beginners' yarn is lumpy and weak where it is thick. Counting twist is easy: mark an inch, untwist it until the fibers lie parallel, and count the turns.

The studio lab. You will spin your first yarn on a drop spindle, a few yards of wool singles, then count its turns per inch at several places, measure its diameter and calculate its twist angle. Your yarn will be uneven. Every spinner's first yarn is. You will measure that unevenness and spin again.

PICTURE STUDY



Old Woman Spinning, Nicolaes Maes, c. 1655 · Oil on panel · Rijksmuseum, Amsterdam
Image: [Wikimedia Commons](#), public domain

Nicolaes Maes, a pupil of Rembrandt, painted quiet scenes of old age and household work in Dordrecht. Here an elderly woman sits at her spinning wheel, absorbed in the thread running through her fingers. Dutch viewers saw in such pictures the virtue of diligent work.

Look closely

- Find the fiber she is spinning. Is it held on a distaff, and does it look like wool or flax?
- Follow the thread from her fingers to the wheel. Where is twist being added, and where is yarn being wound?
- Look at her hands. Which hand drafts and which controls the twist?
- Find the light source. How does Maes draw your eye to the thread?

Talk about it

1. Spinning was so constant that older women spun nearly all day. Using worked example 3, estimate how many yards she might spin in an hour.
2. Why might a painter choose an old spinner as a picture of a faithful life?
3. Compare her wheel with the drop spindle you used. What has she gained, and what has she given up?

Safety first. A homemade spindle shaft should have smooth, rounded ends; sand any splinters. Keep the spinning area clear so a dropped spindle does not trip anyone. Wash hands after handling raw or oiled wool. Count pins and needles at the end of the session.

First Yarn on the Drop Spindle

Question: How even is your first handspun yarn, and how does its twist compare with a commercial yarn? You will spin several yards of wool singles, measure turns per inch and diameter along its length, and calculate twist angles.

You will need

- A drop spindle (or a ¼-inch dowel 10 in long pushed through a CD or wooden wheel, with a small cup hook screwed in the top)
- 2 oz of wool roving (a medium wool such as Corriedale is easiest)
- A 2-ft leader of plain yarn, a ruler, the 10× magnifier and a commercial worsted-weight wool yarn for comparison

A HOMEMADE DROP SPINDLE AND A FIRST SKEIN

Finished size: A spindle about 10 in long and 5–10 yd of singles · 20 minutes to build; an hour to spin

Fabric and notions

- A ¼-inch (6 mm) hardwood dowel, 10 in long
- An old CD or a 2–3 in wooden wheel for the whorl, with two rubber faucet washers or a dab of glue to hold it
- A small cup hook
- 2 ft of plain wool or cotton yarn for a leader, and 2 oz of wool roving

How to make it

1. Sand both ends of the dowel smooth. Screw the cup hook into one end.
2. Push the dowel through the CD's hole until the CD sits 2 in below the hook (a top-whorl spindle). Fix it with a washer above and below, or a ring of glue.
3. Tie the leader to the shaft just above the whorl, wind a few turns, bring it up and catch it in the hook.
4. Split a 12-in length of roving lengthwise into a strip about as thick as your finger and fluff the end. Overlap it with the leader's end.
5. Spin the spindle clockwise (for Z twist) and let twist run into the overlap to join it. Park the spindle between your knees, draft a few inches, release, and spin again.
6. When the spindle nears the floor, unhook the yarn, wind it onto the shaft above the whorl, re-hook and continue.
7. Wind your finished singles into a small skein around your hand or a book and tie it in two places.

Fabric check: A medium wool roving with a staple of 3–5 inches is easiest; very fine merino and very short fibers are harder at first. Wool-sensitive students can spin a cotton or a soy or bamboo roving, though cotton's short staple needs a lighter spindle and more twist.

Steps

1. **Hypothesis.** Predict whether your yarn's TPI will be higher or lower than the commercial yarn's, and how much it will vary.
2. Build the spindle and spin at least 5 yards following the pattern card. Expect lumps and breaks; rejoin and keep going.
3. Choose five places along your yarn, including one thick and one thin spot. At each, measure the diameter with the ruler under the magnifier (or count how many yarn widths fit side by side across ½ inch).
4. At each place, mark 1 inch, untwist it until the fibers lie parallel, and count the turns. Record TPI.
5. Do the same at three places on the commercial yarn.
6. Calculate the twist angle at each place and the mean and range of TPI for both yarns.
7. **Conclude.** Where did your yarn have the most twist, thick spots or thin? How did your yarn compare with the commercial one?
8. **Repeat round.** Spin another 2 yards trying to draft evenly to the thickness of the commercial yarn. Measure again. Did your range shrink?

Tips

- “Park and draft” is the beginner's method: spin, trap the spindle between your knees, draft, then let the twist in. It keeps the spindle from dropping before you are ready.
- If the yarn keeps drifting apart, it needs more twist; if it kinks back on itself, it has too much.
- Older students: try a supported spindle in a bowl, or a borrowed wheel, and compare TPI.

Check your work

- ☐ I spun at least 5 yards of continuous singles on a spindle I built or borrowed.
- ☐ I measured TPI and diameter at five places and calculated twist angles.
- ☐ I compared my yarn with commercial yarn and improved my evenness in a second round.

LAB NOTEBOOK

1. Draw a drop spindle and label shaft, whorl, hook, leader, singles and roving. Draw arrows for the direction of spin and twist.
2. Draw an S-twist and a Z-twist yarn side by side, with the fiber slant matching the letter.
3. Tape in 6 inches of your first yarn and 6 inches of your improved yarn with their TPI ranges.

KEY FORMULAS

$$\tan \theta = \pi d T \quad (d \text{ in inches, } T \text{ in turns per inch})$$

$$\tan \theta = \pi d T \quad (d \text{ in inches, } T \text{ in turns per inch})$$

$$TPI = \frac{\text{turns counted}}{\text{length in inches}}$$

$$TPI = \frac{\text{length in inches}}{\text{turns counted}}$$

From history. Spinning on spindles never stopped. In parts of the Andes, Africa and Asia, people still spin while walking and herding, much as the women of the Bible did, and many hand spinners in America and Europe today use spindles for their portability and the fine, even yarns a skilled spinner can make on them.

WORKED EXAMPLES

Example 1. You untwist three 1-inch sections of your yarn and count 4, 6 and 5 turns. Its diameter is about 0.08 in. Find the mean TPI and the twist angle.

Show solution

$$1. \text{ Mean: } \frac{4 + 6 + 5}{3} = 5 \text{ TPI} \quad 4 + 6 + 5 = 5 \text{ TPI.}$$

$$2. \tan \theta = \pi \times 0.08 \text{ in} \times 5 \text{ turns/in} = 1.257 \quad \tan \theta = \pi \times 0.08 \text{ in} \times 5 \text{ turns/in} = 1.257.$$

$$3. \theta = \tan^{-1}(1.257) \approx 51^\circ \quad \theta = \tan^{-1}(1.257) \approx 51^\circ.$$

Answer: 5 TPI and a twist angle of about 51° , a firm, hard-twisted yarn. Commercial knitting yarns are often softer, around 20° – 30° .

Example 2. A machine-spun yarn of diameter 0.03 in has a twist angle of 25° . What is its TPI?

Show solution

$$1. T = \frac{\tan \theta}{\pi d} = \frac{\tan 25^\circ}{\pi \times 0.03 \text{ in}} \quad T = \frac{\tan \theta}{\pi d} \quad \tan \theta = \pi \times 0.03 \text{ in} \tan 25^\circ.$$

$$2. T = \frac{0.466}{0.0942 \text{ in}} \approx 4.9 \text{ TPI} \quad T = 0.0942 \text{ in} \times 0.466 \approx 4.9 \text{ TPI.}$$

Answer: About 5 TPI.

Example 3. A flyer wheel's drive wheel is 22 in across and its whorl 2 in across. The spinner treadles 60 times a minute and draws out 20 in of yarn a minute. Find the flyer's speed and the TPI.

Show solution

1. Ratio: $22 \div 2 = 11$ $22 \div 2 = 11$, so the flyer turns 11 times per treadle.
2. Flyer speed: $60 \times 11 = 660$ turns/min $60 \times 11 = 660$ turns/min.
3. TPI: $\frac{660 \text{ turns/min}}{20 \text{ in/min}} = 33 \text{ TPI}$ $20 \text{ in/min} \div 660 \text{ turns/min} = 33 \text{ TPI}$.

Answer: 660 turns a minute and 33 TPI, a fine, tightly twisted thread. To spin softer yarn, draw out faster or use a larger whorl.

PRACTICE

1. **Easy** What does the whorl of a drop spindle do?

Show answer

It adds weight and momentum so the spindle keeps turning (a flywheel).

2. **Easy** How do you tell S twist from Z twist?

Show answer

By the slant of the surface fibers: matching the middle stroke of an S or of a Z.

3. **Easy** Quote Proverbs 31:19.

Show answer

She layeth her hands to the spindle, and her hands hold the distaff.

4. **Medium** You count 18 turns in 4 inches. Find the TPI.

Show answer

$$18/4 = 4.5 \text{ TPI} \quad 18/4 = 4.5 \text{ TPI}$$

5. **Medium** Find the twist angle of a 0.05 in yarn with 6 TPI.

Show answer

$$\tan \theta = \pi(0.05)(6) = 0.942 \quad \tan \theta = \pi(0.05)(6) = 0.942; \theta \approx 43^\circ \quad \theta \approx 43^\circ.$$

6. **Medium** Why does twist run into the thin places of a handspun yarn first?

Show answer

Thin places resist twisting less (less fiber to turn), so twist accumulates there and leaves thick spots soft.

7. **Medium** What advantage did the flyer wheel have over the great wheel?

Show answer

It twisted and wound on at the same time, so spinning was continuous and both hands could draft.

8. **Hard** Two yarns have the same twist angle; one is twice the diameter of the other. Compare their TPI.

Show answer

The thicker yarn has half the TPI, since $T = \tan \theta / (\pi d)$ $T = \tan \theta / (\pi d)$.

9. **Hard** A wheel with ratio 8:1 is treadled 70 times a minute while 35 in of yarn is drawn out. Find the TPI.

Show answer

$$8 \times 70 = 560 \quad 8 \times 70 = 560 \text{ turns per minute}; 560/35 = 16 \text{ TPI} \quad 560/35 = 16 \text{ TPI}.$$

10. **Hard** A spinner wants 10 TPI from the same wheel (8:1, 70 treadles a minute). How fast must she draw out?

Show answer

$$560/10 = 56 \text{ in/min} \quad 560/10 = 56 \text{ in/min}.$$

11. **Challenge** Explain from the physics of twist why a staple yarn needs twist but a filament yarn of silk or nylon can be used with almost none.

Show answer

Staple fibers are short and hold only by friction, which twist creates by pressing them together under tension. Filaments run the full length of the yarn, so each carries load end to end with no need for friction between fibers; a little twist just keeps them together.

COMMON MISTAKES

- Letting the spindle spin backward after it stops. It untwists the yarn and drops; park it before it reverses.
- Drafting too thick a strip at once. Thin, even drafting makes even yarn.
- Counting twist on a plied yarn as if it were singles. Separate the plies first, or count the ply twist separately.

Make it a game · Spindle Spin-Off. Each player gets the same length of roving and three minutes. Spin as much continuous singles as you can. Then measure: one point per foot of yarn, minus a point for each break, plus two bonus points to whoever's yarn has the most even TPI at three checks. Grandparents who learned on a wheel are allowed to coach.

Scripture. “She layeth her hands to the spindle, and her hands hold the distaff.” (Proverbs 31:19, KJV)

Spindle and distaff were the tools of every household in Scripture's world. The patient work of drafting and twisting, inch by inch, is the work Proverbs honors as strength and wisdom.

4.2 HARGREAVES, ARKWRIGHT AND CROMPTON

OBJECTIVES

- Describe the spinning jenny, the water frame and the spinning mule and explain how each changed yarn and work.
- Explain why twist strengthens yarn only up to an optimum and what happens beyond it.
- Run the unit's twist-and-strength lab and calculate turns per inch and spindle output.

Warm-up. Take a 12-inch strip of wool roving. Pull it apart gently: how much force does it take? Now twist a second strip 20 times and pull again. Predict: what would happen with 200 twists?

WATCH

Spinning Mule Demonstration at Leeds Industrial Museum

[leedsmuseums](#) · 6:38

<https://www.youtube.com/watch?v=81PydkdYQws>

WHEN TO WATCH

After “How they figured it out.” Watch the carriage of the mule draw out and twist, then run back and wind on. Count the spindles if you can.

BACKUP VIDEO

Monticello Spinning Jenny Operation

[Thomas Jefferson's Monticello](#) · 1:38

https://www.youtube.com/watch?v=6CfhB9m_BJg

A working reproduction of Hargreaves's spinning jenny at Thomas Jefferson's Monticello, for comparison with the mule.

KEY TERMS

spinning jenny

James Hargreaves's hand-powered machine (c. 1764) that spun many threads at once, at first eight, from a moving carriage.

spinning mule

Samuel Crompton's machine (1779) combining the jenny's moving carriage with the water frame's rollers, able to spin fine, strong yarn.

optimum twist

The amount of twist that gives a staple yarn its greatest strength; less lets fibers slip, more tilts them away from the load.

water frame

Richard Arkwright's spinning machine (patented 1769), powered by a water wheel, which drew out roving between pairs of rollers turning at different speeds and spun a strong, firm warp yarn.

roller drafting

Drawing out fibers by passing them between pairs of rollers, each pair turning faster than the one before.

factory system

Gathering workers and power-driven machines under one roof, with set hours and supervision, instead of spinning and weaving at home.

CORE IDEAS

The story. In 1733 John Kay's flying shuttle let a weaver throw the weft across the loom much faster, and soon spinners could not keep up. Around 1764 James Hargreaves, a Lancashire weaver, built the spinning jenny, which let one person turn a wheel and spin eight threads at once; later jennies had dozens. In 1769 Richard Arkwright patented the water frame, and in 1771 he built a water-powered mill at Cromford in Derbyshire, often called the first true factory. In 1779 Samuel Crompton, working in secret at home, combined the jenny and the water frame in a hybrid he called the mule, which spun yarn fine and strong enough for muslins once imported only from India.

How they figured it out. Each machine solved one weakness. The jenny copied the hand spinner's motions with many spindles in a row and a sliding carriage that drew out the roving; its yarn was soft and fit only for weft. Arkwright's frame borrowed an earlier

idea, roller drafting, in which fibers pass between pairs of rollers, each pair turning faster than the last, drawing the roving finer before twist reaches it; its yarn was firm and strong enough for warp. Crompton's mule drew out with rollers, then stretched and twisted further on a moving carriage, letting twist even out the thin places before winding on. The combination gave fine, even, strong yarn, and the mule spun most of Britain's fine cotton for a century.

The fabric science. Twist makes staple yarn strong by squeezing fibers together so friction holds them. But twist has a cost: each surface fiber lies at an angle to the yarn's axis, so only part of its strength pulls along the axis. At low twist, fibers slip past each other before they break: the yarn pulls apart. As twist rises, friction grows and strength climbs. Past an optimum, the fibers are tilted so far that the yarn breaks with each fiber carrying load inefficiently, and very high twist also makes yarn hard, kinky and lean. Plot breaking load against twist and you get a rising curve that levels off and falls. Spinners choose twist below the optimum for soft knitting yarns and near it for strong warps and threads.

The human side. Machines multiplied output many times over, made cotton cloth cheap enough for ordinary families, and created new jobs; but they also ended the household spinning that had supported rural families, and in the new mills children as young as seven worked long hours. The next lesson tells that history in America.

The studio lab. This is the unit's twist-and-strength lab. You will put different amounts of twist into identical lengths of wool roving, from none to a great deal, and load each until it breaks. Graphing breaking load against turns per inch should show you the optimum with your own hands.

PICTURE STUDY



Arkwright's Mills, Joseph Wright of Derby, c. 1795–96 · Oil on canvas · Derby Museum and Art Gallery
Image: [Wikimedia Commons](#), public domain

Joseph Wright of Derby painted Arkwright's cotton mills in the steep valley of the River Derwent at Cromford, Derbyshire. The tall, many-windowed mill stands in a wild landscape of cliffs and woods. Wright also painted the mills lit up at night, for they ran in shifts around the clock, a sight never seen before.

Look closely

- Count the rows of windows. Why would a spinning mill need so much light?
- Find the river. What powered the machines?
- Look at the cliffs and woods around the mill. How does Wright show a new kind of building in an old landscape?
- Find the road and the carriage. How would cotton arrive and yarn leave?

Talk about it

1. Arkwright's mills also ran at night by candle and lamp, near cotton fluff. What dangers would that bring?
2. Who do you think worked the long shifts in these mills?
3. Is this painting a celebration, a warning, or both?

Safety first. Clip roving strips firmly and hang the bucket over a soft surface; keep feet clear. If you use a hand drill to add twist, unplugged and cordless drills only, run it slowly, keep hair tied back, and hold the strip away from your face.

STUDIO LAB

The Twist-and-Strength Lab

Question: How does the amount of twist affect the strength of a staple yarn, and where is the optimum? You will twist identical strips of roving to set turns and break them with the bucket rig.

You will need

- Wool pencil roving or a thin, even strip of wool roving (about 1 oz)
- Two binder clips, a ruler, a marker, the dowel and bucket rig, the scale and a measuring cup
- A helper, or a hand-cranked egg beater or cordless drill with a hook to add twist

Steps

1. **Hypothesis.** Sketch the shape you expect for breaking load against TPI.
2. Cut 14 strips of roving, each 14 in long, as even in thickness as possible; weigh each and discard any more than 10% off the average.
3. Mark a 10-inch gauge length on each. Clip one end of a strip to a fixed point and twist the other end a set number of turns: two strips each at 0, 10, 20, 40, 60, 80 and 120 turns.
4. Without letting the twist out, clip the strip to the dowel and hang the bucket from the lower clip at the gauge mark.
5. Pour water in slowly until the strip breaks. Weigh the bucket and water and record the breaking load and how it failed: slipped apart, or snapped.
6. Calculate TPI and the mean breaking load at each twist level. Graph load against TPI.
7. **Conclude.** Where is your optimum? How did the way the strips failed change as twist increased?
8. **Repeat round.** Run two more strips at the twist levels on either side of your optimum to locate it more closely.

Tips

- Keep the twist in: clip the twisted end before you let go.
- Untwisted roving pulls apart at a few grams; add a light cup and weigh carefully.
- Real yarns are drafted much finer than roving, so their optimum TPI is higher, but the curve has the same shape.

Check your work

- ☐ I changed only twist and controlled strip length, weight and loading method.
- ☐ I graphed mean breaking load against TPI and identified the optimum.
- ☐ I described how failure changed from slipping to breaking.

LAB NOTEBOOK

1. Draw simple side views of the jenny, the water frame and the mule, labeling where drafting, twisting and winding happen in each.
2. Paste your twist-and-strength graph and mark the optimum.
3. Write one paragraph on what a Lancashire cottage spinner of 1790 might have thought of the mill.

KEY FORMULAS

$$\text{TPI} = \frac{\text{turns added}}{\text{gauge length (in)}}$$

$$\text{TPI} = \text{gauge length (in)} \times \text{turns added}$$

$$\text{delivery rate} = \frac{\text{spindle speed (turns/min)}}{\text{TPI}}$$

$$\text{delivery rate} = \text{TPI} \times \text{spindle speed (turns/min)}$$

From history. Crompton never patented his mule, partly because he could not afford to, and he made it public for a small subscription from manufacturers. In 1812 Parliament granted him £5,000 in recognition, far less than his invention was worth to the nation's mills.

WORKED EXAMPLES

Example 1. Roving strips with a 10-inch gauge length are given 0, 20, 40, 60, 80 and 120 turns. Their breaking loads are 40, 310, 520, 600, 560 and 410 g. Find the TPI of each and the optimum.

Show solution

1. $\text{TPI} = \text{turns} \div 10 \text{ in}$: 0, 2, 4, 6, 8, 12 TPI 0, 2, 4, 6, 8, 12 TPI.
2. The largest load, 600 g, is at 6 TPI 6 TPI; loads fall at 8 and 12 TPI.

Answer: Optimum near 6 TPI for this roving. Beyond it, extra twist lowered the strength.

Example 2. A water-frame spindle turns at 2,400 turns per minute and spins yarn at 16 TPI. How many inches of yarn does one spindle deliver per minute, and how many yards in a 12-hour day?

Show solution

1. Delivery: $\frac{2,400 \text{ turns/min}}{16 \text{ turns/in}} = 150 \text{ in/min}$ 16 turns/in 2,400 turns/min = 150 in/min.
2. Per day: $150 \times 60 \times 12 = 108,000 \text{ in} = 3,000 \text{ yd}$ $150 \times 60 \times 12 = 108,000 \text{ in} = 3,000 \text{ yd}$.

Answer: 150 in a minute, 3,000 yards a day from one spindle, on these assumed figures.

Example 3. A cottage spinner on a wheel spins about 400 yards of fine cotton a day. How many cottage spinners equal one frame of 96 spindles at 3,000 yards per spindle per day?

Show solution

1. Frame output: $96 \times 3,000 = 288,000 \text{ yd}$ $96 \times 3,000 = 288,000 \text{ yd}$.
2. Spinners: $288,000 \div 400 = 720$ $288,000 \div 400 = 720$.

Answer: About 720 hand spinners for one frame, on these figures, which is why the mills transformed the trade so fast.

PRACTICE

1. **Easy** Match each inventor to his machine and date: Hargreaves, Arkwright, Crompton.

Show answer

Hargreaves: spinning jenny, c. 1764. Arkwright: water frame, patented 1769. Crompton: mule, 1779.

2. **Easy** Which invention of 1733 made weavers outrun spinners?

Show answer

John Kay's flying shuttle.

3. **Easy** Why was water-frame yarn suited to warp and jenny yarn mostly to weft?

Show answer

Roller-drafted water-frame yarn was firm and strong; jenny yarn was soft and weaker.

4. **Medium** A 12-inch strip gets 54 turns. Find the TPI.

Show answer

$$54/12 = 4.5 \text{ TPI} \quad 54/12 = 4.5 \text{ TPI}$$

5. **Medium** A spindle turns 3,600 times a minute; the yarn has 20 TPI. Find the delivery in inches per minute.

Show answer

$$180 \text{ in/min} \quad 180 \text{ in/min}$$

6. **Medium** Explain why too much twist weakens a yarn.

Show answer

Surface fibers tilt so far from the axis that only part of their strength pulls along the yarn, and the yarn becomes hard and kinked.

7. **Medium** What did Crompton's mule combine, and why was its yarn so fine and even?

Show answer

The water frame's roller drafting and the jenny's moving carriage; the carriage stretched and twisted the yarn further, evening out thin places before winding.

8. **Hard** From worked example 1, by what percent did strength drop from the optimum to 12 TPI?

Show answer

$$(600 - 410)/600 \approx 31.7\% (600 - 410)/600 \approx 31.7\%$$

9. **Hard** A mule with 600 spindles runs 2,000 turns a minute at 25 TPI for 10 hours. How many miles of yarn is that? (1 mile = 63,360 in)

Show answer

Per spindle 80 in/min; total $80 \times 600 \times 600 = 28,800,000$ in ≈ 455 mi

10. **Hard** Why would a knitting-yarn maker deliberately choose twist below the optimum?

Show answer

Lower twist gives a softer, loftier, warmer yarn with better hand; full strength is not needed in a sweater.

11. **Challenge** Cheaper yarn helped millions of families afford cloth, yet the same machines ended cottage spinning and drew children into mills. Write a balanced paragraph weighing these outcomes.

Show answer

A good answer credits the real gains (cheap cloth, new industries, rising output) and the real costs (lost household income, long factory hours, child labor), and notes that laws, reform and better machines later reduced the harms.

COMMON MISTAKES

- Thinking more twist always means stronger yarn. Strength peaks and then falls.
- Testing strips of different thickness. Weigh strips and keep them alike.
- Crediting one inventor with the whole change. Kay, Paul and Wyatt, Hargreaves, Arkwright and Crompton each solved part of it.

Make it a game · Machine Match. Write each invention (flying shuttle, spinning jenny, water frame, mule, flyer wheel, drop spindle) on a card and each fact (inventor, date, power source, what it solved) on separate cards. Shuffle and race to rebuild the sets. Fastest correct table wins; a wrong pair costs ten seconds.

4.3 SLATER, LOWELL AND THE MILL

OBJECTIVES

- Tell how Samuel Slater and Francis Cabot Lowell brought mill spinning and weaving to America, and describe life for the Lowell mill girls.
- Describe child labor in American mills plainly, including Lewis Hine's photographs and how laws changed.
- Measure a skein's yardage and grist and calculate yards per pound, production and working hours.

Warm-up. Look at the label of the oldest piece of clothing in your house and the newest. Where was each made? Then guess: in 1840, where would a New England family's cotton cloth have been spun and woven?

WATCH

The Massachusetts Mill Workers, Lowell National Historical Park

Prairie Public · 6:31

<https://www.youtube.com/watch?v=zSVk6axNHkQ>

WHEN TO WATCH

After “How they figured it out.” Listen for how the mill girls were recruited, how many hours they worked, why they came, and what changed later.

BACKUP VIDEO

Slater Mill and Water Power

Blackstone River Valley National Historical Park · 4:06

<https://www.youtube.com/watch?v=LYGW0bulC7M>

A ranger at Slater Mill explains how the river powered the machines.

KEY TERMS

Slater Mill

The cotton-spinning mill at Pawtucket, Rhode Island, built in 1793 by Samuel Slater and his partners, now part of a national historical park.

mill girls

The young, mostly unmarried farm women from New England who worked in the Lowell mills in the 1820s–1840s and lived in company boarding houses.

skein

A loosely coiled length of yarn of known length, wound on a reel.

integrated mill

A mill that spins and weaves under one roof, from bale to cloth; the Boston Manufacturing Company at Waltham (1814) was the first in America.

child labor

The employment of children in hard, long, often dangerous work, common in American mills until reform laws of the early 1900s.

grist

A yarn's length per unit of weight, often given in yards per pound.

CORE IDEAS

The story. Britain guarded its new spinning machines, forbidding the export of machinery and plans and the departure of skilled mill workers. Samuel Slater had served an apprenticeship with Jedediah Strutt, Arkwright's partner, in Belper, and he carried the design of Arkwright's machinery in his memory. In 1789, at twenty-one, he sailed for America without announcing his trade. In Providence he joined the merchants William Almy and Moses Brown, rebuilt the machines from memory, and in 1790 began spinning cotton with water power at Pawtucket, Rhode Island. In 1793 the firm built the mill that still stands there. Its first workers were children, as in English mills, and Slater's system of hiring whole families spread across southern New England.

How they figured it out. Twenty years later the Boston merchant Francis Cabot Lowell toured British mills and, like Slater, memorized what he saw, especially the power loom. With the mechanic Paul Moody he built American power looms, and in 1814 the

Boston Manufacturing Company at Waltham, Massachusetts, became the first mill in America to turn raw cotton into finished cloth under one roof. After Lowell's death in 1817 his partners built a whole new mill city on the Merrimack River and named it for him. To staff it they recruited young women from New England farms, who lived in supervised boarding houses, attended church and lectures, and earned cash wages, many sending money home or saving for a brother's education. Some wrote for their own magazine, the *Lowell Offering*.

The honest picture. Mill work was hard. Lowell girls worked about twelve to thirteen hours a day, six days a week, in hot, humid rooms full of cotton dust and the roar of hundreds of looms. When owners cut wages in the 1830s, the women walked out, and in the 1840s they petitioned the Massachusetts legislature for a ten-hour day. Over time, families arriving from Ireland and French Canada replaced the farm girls at lower wages. In the Southern mills that grew after the Civil War, children worked at the spinning frames as doffers and spinners. Between 1908 and 1917 the photographer Lewis Hine, working for the National Child Labor Committee, photographed children in mills across the country, among them twelve-year-old Addie Card at a mill in Vermont. His pictures helped persuade states and finally Congress, in the Fair Labor Standards Act of 1938, to forbid most factory work by young children.

The fabric science. A mill thinks in length and weight. Yarn is reeled into skeins of known length and weighed, and its grist (yards per pound) tells how fine it is and how much cloth it will make. A spinning room's output is $\text{spindles} \times \text{speed} \div \text{twist}$, and a weaver's output is $\text{picks per minute} \div \text{picks per inch}$. Those simple ratios set wages, schedules and prices, and they still run every textile mill.

The studio lab. You will wind your handspun and two commercial yarns into skeins of measured length, weigh them, and calculate their grist. Then you will time yourself spinning and compare your yards per hour with a single mill spindle, to feel in your own hands why the mills won.

PICTURE STUDY



The Morning Bell, Winslow Homer, c. 1871 · Oil on canvas · Yale University Art Gallery, New Haven

Image: [Wikimedia Commons](#), public domain

Winslow Homer painted young women walking to work at a New England mill as its bell rings in the morning. The mill bell set the day's hours: when to rise, when to start, when to eat, when to stop. Homer lets us watch the walk to work rather than the work itself.

Look closely

- Find the bell or the mill building. How does the path lead toward it?
- Look at the women's clothes and the lunch pails or baskets they carry. What do they tell you about the workday?
- Notice who walks alone and who walks together. What mood does each figure suggest?
- Find the dog or any other detail that makes the scene feel ordinary.

Talk about it

1. Compare this painting's mood with the Lowell girls' petitions for a ten-hour day. What does Homer show, and what does he leave out?

2. Why would a mill run by a bell rather than by sunrise and sunset?
3. If you walked this path at 5 a.m. six days a week, what would you hope the mill would change?

Safety first. Wind skeins around chair backs or a niddy-noddy, not around a person's neck or hands for long periods. Keep the work area clear so yarn and chairs do not trip anyone. Count pins and needles at the end of the session.

STUDIO LAB

Skein, Grist and the Mill's Arithmetic

Question: How fine is your handspun compared with commercial yarns, and how many hand spinners does one mill spindle replace? You will measure yardage and weight, calculate grist, and time your own spinning.

You will need

- Your handspun singles from Lesson 4.1 plus more roving and your spindle
- Two commercial yarns of different weights (for example, a fingering and a bulky)
- A niddy-noddy or two chair backs set exactly 1 yd apart, the 0.1 g scale, scrap yarn for ties and a timer

Steps

1. **Hypothesis.** Predict the grist of your handspun and of each commercial yarn, and how many minutes you need to spin 10 yards.
2. Wind each yarn around the chair backs or niddy-noddy, counting wraps. Each wrap around two chairs 1 yd apart is 2 yd.
3. Tie each skein loosely in four places, slip it off, and weigh it to 0.1 g.
4. Calculate yardage and grist in yards per pound for each yarn. Compare the commercial grists with the yardage printed on their labels.
5. Time yourself spinning exactly 10 yards of singles. Calculate your rate in yards per hour.
6. Using a mill spindle rate of 150 in per minute, calculate how many of you one spindle equals, and how many of you a frame of 128 spindles equals.
7. **Conclude.** What does your number say about why cottage spinning disappeared after the mills came?
8. **Repeat round.** Time another 10 yards. Did practice change your rate, and by what percent?

Tips

- Wind under light, even tension; stretching the yarn while winding inflates the yardage.
- Commercial labels give yardage per ball. Your measured grist should come within a few percent of it.
- Keep your skeins for Lesson 4.4, where you will convert grist to tex and other count systems.

Check your work

- ☐ I measured yardage and weight for three yarns and calculated grist correctly.
- ☐ I compared my measured grist with a label and explained any difference.
- ☐ I calculated how many hand spinners equal one mill spindle and one frame.

LAB NOTEBOOK

1. Draw a timeline from Kay's flying shuttle (1733) to the Fair Labor Standards Act (1938), with at least eight events from Lessons 4.2–4.3.
2. Tape a 6-inch sample of each skein with its grist written beside it.
3. Write a short letter as a Lowell girl in 1845 describing one day, using real details from the lesson.

KEY FORMULAS

$$\text{grist (yd/lb)} = \frac{\text{length in yards}}{\text{weight in pounds}} = \frac{\text{length in yards} \times 453.6}{\text{weight in grams}}$$

$$\text{grist (yd/lb)} = \text{weight in pounds} \times \text{length in yards} = \text{weight in grams} \times \text{length in yards} \times 453.6$$

$$\text{output} = \text{rate} \times \text{time}$$

$$\text{output} = \text{rate} \times \text{time}$$

From history. Slater Mill, the Boott Mills in Lowell and the boarding houses beside them are preserved by the National Park Service in the Blackstone River Valley and Lowell national historical parks. At Lowell, a weave room of working looms still runs, so visitors can hear the noise the mill girls worked in all day.

WORKED EXAMPLES

Example 1. Your handspun skein is 18 yd long and weighs 22 g. Find its grist in yards per pound.

Show solution

$$1. \text{ grist} = \frac{18 \text{ yd} \times 453.6 \text{ g/lb}}{22 \text{ g}} = 371 \text{ yd/lb} \quad \text{grist} = 22 \text{ g} \times 453.6 \text{ g/lb} = 371 \text{ yd/lb}.$$

Answer: About 370 yards per pound, a bulky yarn. Worsted-weight knitting yarn is often around 900–1,000 yd/lb.

Example 2. A Lowell weaver in 1840 tends two looms, each weaving 100 picks a minute, cloth at 60 picks per inch, for a 12½-hour day with 1½ hours stopped. How many yards of cloth does she produce?

Show solution

$$1. \text{ Running time: } 12.5 - 1.5 = 11 \text{ h} = 660 \text{ min} \quad 12.5 - 1.5 = 11 \text{ h} = 660 \text{ min}.$$

$$2. \text{ Per loom: } \frac{100 \text{ picks/min}}{60 \text{ picks/in}} \times 660 \text{ min} = 1,100 \text{ in} \approx 30.6 \text{ yd} \quad 100 \text{ picks/min} \times 660 \text{ min} = 1,100 \text{ in} \approx 30.6 \text{ yd}.$$

$$3. \text{ Two looms: } \approx 61 \text{ yd} \approx 61 \text{ yd}.$$

Answer: About 61 yards a day, on these assumed figures.

Example 3. Mill girls worked about 73 hours a week; the ten-hour movement asked for 60. By what percent would that cut the week? For how many hours a year is that over 50 working weeks?

Show solution

$$1. \text{ Cut: } \frac{73 - 60}{73} \times 100\% = 17.8\% \quad 73 - 60 \times 100\% = 17.8\%.$$

$$2. \text{ Hours saved per year: } 13 \times 50 = 650 \text{ h} \quad 13 \times 50 = 650 \text{ h}.$$

Answer: About an 18% shorter week, 650 fewer hours a year at the looms.

PRACTICE

1. **Easy** In what year and town did Slater begin water-powered cotton spinning in America?

Show answer

1790, Pawtucket, Rhode Island.

2. **Easy** What was special about the Boston Manufacturing Company at Waltham (1814)?

Show answer

It was the first American mill to spin and weave under one roof, from raw cotton to cloth.

3. **Easy** Who photographed child workers in American mills for the National Child Labor Committee?

Show answer

Lewis Hine.

4. **Medium** A skein of 40 yd weighs 18 g. Find its grist.

Show answer

$$40 \times 453.6 / 18 \approx 1,008 \text{ yd/lb} \quad 40 \times 453.6 / 18 \approx 1,008 \text{ yd/lb}$$

5. **Medium** How many yards are in a 100 g ball of yarn with a grist of 900 yd/lb?

Show answer

$$900 \times 100 / 453.6 \approx 198 \text{ yd} \quad 900 \times 100 / 453.6 \approx 198 \text{ yd}$$

6. **Medium** Name two reasons New England farm women came to work at Lowell.

Show answer

Cash wages (to save, send home, or pay for a brother's schooling), independence and educational opportunities such as lectures and libraries.

7. **Medium** What law of 1938 set national limits on child labor in factories?

Show answer

The Fair Labor Standards Act.

8. **Hard** You spin 12 yd of singles in 40 minutes. A mill spindle delivers 150 in a minute. How many of you equal one spindle?

Show answer

You: 0.3 yd/min ; spindle $150/36 \approx 4.17 \text{ yd/min}$; about 14 of you.

9. **Hard** A weaver's loom runs 120 picks a minute on cloth of 72 picks per inch for 10 h. How many yards?

Show answer

$$120 / 72 \times 600 = 1,000 \text{ in} \approx 27.8 \text{ yd} \quad 120 / 72 \times 600 = 1,000 \text{ in} \approx 27.8 \text{ yd}$$

10. **Hard** Why did British law try to keep mill workers like Slater from leaving the country?

Show answer

To protect Britain's lead in mechanized spinning; machines could be copied from a skilled worker's knowledge even without drawings.

11. **Challenge** Hine's photographs changed laws. Explain how a picture can do what statistics alone sometimes cannot, and name one responsibility a photographer has to his subjects.

Show answer

A face and a name make a hard fact personal and undeniable, moving people who ignore numbers. A photographer must tell the truth (no staging or exaggeration), respect the dignity of the people shown, and use the picture for their good.

COMMON MISTAKES

- Telling the mill story as either all progress or all misery. The mills gave wages and cheap cloth and also long hours, dust, danger and child labor; tell both.
- Counting one wrap around two chairs as one yard. Around two chairs 1 yd apart, each full wrap is 2 yd.
- Confusing grist (length per weight) with yarn count systems that use weight per length. Lesson 4.4 sorts them out.

Make it a game • Mill Bell Math. A parent rings a bell (or claps) and calls out a mill problem: "One spindle, 2,400 turns a minute, 20 TPI: inches per minute?" First correct answer scores a point; the winner of each round becomes the bell-ringer and must make up the next problem. Five rounds to a shift.

4.4 YARN COUNT: DENIER, TEX AND COTTON COUNT

OBJECTIVES

- Distinguish direct (weight per length) and indirect (length per weight) yarn count systems.
- Convert among tex, denier, decitex, cotton count, metric count and yards per pound.
- Measure the tex of several yarns and threads and place them in the Craft Yarn Council's yarn weight system.

Warm-up. Collect three labels: a spool of sewing thread, a ball of knitting yarn and a pair of tights, socks or a jacket that names a denier. Copy every number on each label. Which numbers describe how thick the yarn is?

WATCH

What is Yarn Count II Clear Concept on English Count, Tex, Denier & Metric Counting System

Textile Vlog · 4:33

<https://www.youtube.com/watch?v=MwR23XkxQTM>

WHEN TO WATCH

After “The fabric science.” Pause at each count system and write its definition before the narrator gives an example.

Note: A textile-education channel's clear slide lecture on count systems.

BACKUP VIDEO

What Does Fabric Denier Mean? - Because I Know That - Episode 2

missionspec1 · 2:49

<https://www.youtube.com/watch?v=N6vQeJlJ8AY>

A short explanation of what a fabric's denier means on an outdoor gear label.

KEY TERMS

direct count system

A system giving weight per fixed length: the bigger the number, the heavier the yarn. Tex and denier are direct.

tex

Grams per 1,000 meters of yarn. Decitex (dtex) is grams per 10,000 m.

metric count (Nm)

Kilometers of yarn per kilogram (or meters per gram).

indirect count system

A system giving length per fixed weight: the bigger the number, the finer the yarn. Cotton count, worsted count and metric count are indirect.

cotton count (Ne)

The number of 840-yard hanks in one pound of yarn. A 30s cotton yarn has 30×840 yd in a pound.

wraps per inch (WPI)

How many times a yarn wraps side by side in one inch of a ruler; a quick hand measure of thickness.

CORE IDEAS

The story. Every trade invented its own way to describe yarn. Lancashire cotton spinners counted how many hanks of 840 yards a pound of yarn made. Worsted spinners in Yorkshire used hanks of 560 yards; woolen spinners used still others; silk throwsters counted the weight in deniers (an old French coin) of a standard length of silk. The result was a tangle of systems, and buyers and sellers in different countries often misunderstood each other. In the twentieth century, standards bodies proposed tex, grams per kilometer, as a single universal system, and engineers and thread makers now use it widely, though the old counts are still printed on many labels.

How they figured it out. All count systems answer the same question, how much yarn per how much weight, in one of two directions. *Direct* systems fix the length and weigh it: tex (grams per 1,000 m), decitex (grams per 10,000 m) and denier (grams per 9,000 m). Bigger number, heavier yarn. *Indirect* systems fix the weight and measure the length: cotton count (840-yd hanks per

pound), worsted count (560-yd hanks per pound), metric count (km per kg). Bigger number, finer yarn. Once you know which kind a number is, you can convert any count to any other.

The fabric science. Count is not diameter, because fibers differ in density; a 30 tex polyester yarn is a little thinner than a 30 tex wool yarn. But within one fiber, count tracks thickness, and it lets a spinner set twist, a weaver set ends per inch and a knitter set gauge. Hand knitters use a simpler, looser scale: the Craft Yarn Council's yarn weight classes, from 0 (lace) through 4 (medium, often called worsted) to 7 (jumbo), each with a typical gauge and needle size. Wraps per inch gives a rough check of which weight class a mystery yarn fits.

Conversions to know. Denier = $9 \times \text{tex}$. Decitex = $10 \times \text{tex}$. Metric count Nm = $1,000 \div \text{tex}$. Cotton count Ne = $590.5 \div \text{tex}$ (because 840 yd per lb works out to 590.5 tex-units). Yards per pound = $496,055 \div \text{tex}$. Write the formulas once in your notebook and you can read any label in the world.

The studio lab. You will measure tex directly: weigh carefully measured lengths of your handspun, two knitting yarns and two sewing threads, convert each to the other systems, count wraps per inch, and place each yarn in the yarn weight system.

PICTURE STUDY



Woman Winding Yarn, Vincent van Gogh, 1885 · Oil on canvas · Van Gogh Museum, Amsterdam

Image: [Wikimedia Commons](#), public domain

In Nuenen, in the Netherlands, van Gogh painted the weavers' households around him. Before a weaver could weave, someone, often his wife, had to wind yarn from skeins onto bobbins. Here a woman works at a winding wheel in a dim cottage.

Look closely

- Find the skein of yarn and the reel or swift that holds it. How does the yarn travel from the skein to the bobbin?
- Look at her hands and posture. How long might she sit at this work?
- Notice the colors. How does van Gogh show the dimness of a weaver's cottage?
- Look for other tools or furniture. What do they tell you about the household?

Talk about it

1. A winder needed to know how much yarn was on each bobbin. How would yardage and grist help her?
2. Why was winding a separate job from spinning and weaving?
3. What does van Gogh seem to feel about this woman and her work?

Safety first. Cut thread and yarn with small scissors or snips, carried points down. Wind long lengths over chair backs rather than around fingers. Count pins and needles at the end of the session.

Measuring Tex: Five Yarns and Threads

Question: What is the tex of your handspun, two knitting yarns and two sewing threads, and how do they compare in the other count systems? You will measure, weigh, convert and classify.

You will need

- Your handspun skein, two commercial knitting yarns, an all-purpose polyester sewing thread and a heavy-duty or jeans thread
- A metric tape measure or two chairs 1 m apart, the 0.1 g scale, a ruler and a pencil for wraps per inch
- The Craft Yarn Council chart (see the unit's optional books and tools)

Steps

1. **Hypothesis.** Rank the five by tex and predict each knitting yarn's weight class.
2. Measure off 10 m of each knitting yarn and of your handspun (use your skeins), and 50 m of each thread (25 wraps around chairs 1 m apart). Measure under light, even tension.
3. Weigh each length. For thread, weigh the 50 m bundle; for more precision, weigh 100 m.
4. Calculate tex, denier, Nm, Ne and yd/lb for each. Make one conversion table.
5. Wrap each knitting yarn side by side, without crowding, around a pencil for 1 inch and count wraps per inch.
6. Place each knitting yarn in the yarn weight system using its label, its WPI and its yd/lb, and check that the three agree.
7. **Conclude.** Did your ranking hold? How close were your measured yardages to the labels?
8. **Repeat round.** Re-measure the lightest thread using 100 m. How much did your tex change, and which measurement do you trust more?

Tips

- Small masses need long lengths: 10 m of sewing thread may weigh only 0.3 g, too small for a 0.1 g scale to read well.
- Thread spools often print a tex or a weight number; compare yours with it.
- Keep the table: Lesson 4.5 and Unit 5's gauge and fabric-weight problems use these numbers.

Check your work

- ☐ I measured long enough lengths to weigh accurately and recorded every mass and length.
- ☐ I converted each yarn to four systems correctly.
- ☐ I classified the knitting yarns by three methods and explained any disagreement.

LAB NOTEBOOK

1. Make a two-column chart, Direct and Indirect, listing each system with its definition and an example.
2. Write the conversion formulas in a box you can find all year.
3. Tape in a short length of each measured yarn beside its tex.

KEY FORMULAS

$$\text{tex} = \frac{\text{grams}}{\text{length in km}}, \quad \text{denier} = 9 \times \text{tex}$$

$$\text{tex} = \text{length in km} \times \text{grams}, \quad \text{denier} = 9 \times \text{tex}$$

$$Nm = \frac{1,000}{\text{tex}}, \quad Ne = \frac{590.5}{\text{tex}}$$

$$Nm = \text{tex} \times 1,000, \quad Ne = \text{tex} \times 590.5$$

$$\text{yd/lb} = \frac{496,055}{\text{tex}}$$

$$\text{yd/lb} = \text{tex} \times 496,055$$

From history. The denier began as a small French coin, and silk merchants once weighed a standard skein of silk against such coins. The name survived the coin by centuries and is still printed on stockings, sewing thread and backpack fabric.

WORKED EXAMPLES

Example 1. 25.0 m of a knitting yarn weighs 5.5 g. Find its tex, denier, metric count, cotton count and yards per pound.

Show solution

1. Tex: $\frac{5.5 \text{ g}}{0.025 \text{ km}} = 220 \text{ tex}$ $0.025 \text{ km} \times 220 \text{ tex} = 5.5 \text{ g}$
2. Denier: $9 \times 220 = 1,980 \text{ den}$ $9 \times 220 = 1,980 \text{ den}$; $N_m = 1,000/220 = 4.5$ $N_m = 1,000/220 = 4.5$;
 $N_e = 590.5/220 = 2.7$ $N_e = 590.5/220 = 2.7$.
3. Yards per pound: $496,055/220 \approx 2,255 \text{ yd/lb}$ $496,055/220 \approx 2,255 \text{ yd/lb}$.

Answer: 220 tex = 1,980 denier = $N_m 4.5 = N_e 2.7 \approx 2,255 \text{ yd/lb}$, a light (DK or sport) knitting yarn.

Example 2. A shirt is woven of 40s cotton ($N_e 40$). Find its tex and denier, and the length of yarn in a 150 g shirt.

Show solution

1. Tex: $590.5/40 = 14.8 \text{ tex}$ $590.5/40 = 14.8 \text{ tex}$; denier $9 \times 14.8 = 133$ $9 \times 14.8 = 133$.
2. Length: $\frac{150 \text{ g}}{14.8 \text{ g/km}} = 10.1 \text{ km}$ $14.8 \text{ g/km} \times 10.1 \text{ km} = 150 \text{ g}$

Answer: 14.8 tex (133 denier); a 150 g shirt contains about 10 km, more than 6 miles, of yarn.

Example 3. A 70-denier nylon yarn has 34 filaments. Find its tex, its dtex and the dpf.

Show solution

1. Tex: $70/9 = 7.8 \text{ tex}$ $70/9 = 7.8 \text{ tex}$; dtex 7878.
2. dpf: $70/34 = 2.06$ $70/34 = 2.06$.

Answer: 7.8 tex (78 dtex); about 2 denier per filament. Labels often write this “78 dtex f34.”

PRACTICE

1. **Easy** Is denier a direct or indirect system? Cotton count?

Show answer

Denier: direct. Cotton count: indirect.

2. **Easy** Define tex.

Show answer

Grams per 1,000 meters of yarn.

3. **Easy** Convert 30 tex to denier.

Show answer

270 denier.

4. **Medium** 10.0 m of thread weighs 0.30 g. Find its tex.

Show answer

$0.30/0.010 = 30 \text{ tex}$ $0.30/0.010 = 30 \text{ tex}$

5. **Medium** Convert $N_e 20$ to tex and to metric count.

Show answer

29.5 tex 29.5 tex ; $N_m \approx 33.9$ $N_m \approx 33.9$.

6. **Medium** A yarn is 1,000 yd/lb. Find its tex.

Show answer

$$496,055/1,000 \approx 496 \text{ tex}$$

7. **Medium** Why can a bigger cotton count mean a thinner yarn while a bigger denier means a thicker one?

Show answer

Cotton count is indirect (length per weight: more length per pound means finer); denier is direct (weight per length: more weight means heavier).

8. **Hard** A 100 g ball says 220 yd. Find its tex and its denier.

Show answer

$$220 \text{ yd} = 201.2 \text{ m}; 100/0.2012 \approx 497 \text{ tex}$$

9. **Hard** A fabric needs 2,500 m of 25-tex yarn per square meter. What does the yarn in 1 m² weigh?

Show answer

$$2.5 \text{ km} \times 25 \text{ g/km} = 62.5 \text{ g}$$

10. **Hard** Show that Ne 1 equals about 590.5 tex. (840 yd = 768.1 m; 1 lb = 453.6 g)

Show answer

$$453.6 \text{ g}/0.7681 \text{ km} \approx 590.5 \text{ tex}$$

11. **Challenge** Explain why two yarns of the same tex, one wool and one polyester, are not the same thickness, and estimate which is thicker (wool density 1.31, polyester 1.38 g/cm³).

Show answer

Tex fixes mass per length; volume per length is mass ÷ density, so the less dense wool has slightly more volume and is a little thicker (about $\sqrt{(1.38/1.31)} \approx 2.6\%$ larger diameter, before allowing for air between fibers).

COMMON MISTAKES

- Reading a bigger cotton count as a thicker yarn. Indirect systems run backward.
- Weighing too short a length. Measurement error swamps the result; weigh more yarn.
- Mixing yards and meters in a conversion. Write the unit beside every number.

Make it a game • Count Converter Duel. Two players face off. A parent calls a yarn count (“Ne 30!” or “450 denier!”), and the first player to convert it correctly to tex wins the point. Calculators allowed for the challenge round only. First to seven wins.

4.5 PLY, NOVELTY YARNS AND SEWING THREAD

OBJECTIVES

- Explain singles, plied and cabled yarns, balanced ply, and how ply twist and singles twist work together.
- Describe common novelty yarns and the construction of cotton, polyester and core-spun sewing threads, and choose thread for a job.
- Ply your handspun, measure ply balance and test the breaking strength and tenacity of several threads.

Warm-up. Untwist the end of a piece of kitchen string or a cotton yarn. How many strands is it made of? Untwist one strand: is it made of smaller strands too? Read Ecclesiastes 4:12 and write one sentence about what it might mean for yarn.

WATCH

How DMC Threads are Made

DMC · 4:44

<https://www.youtube.com/watch?v=6M7CtTwGo2o>

WHEN TO WATCH

After “The fabric science.” Watch DMC's historic mill in Mulhouse twist, mercerize, dye and wind cotton thread, and note each finishing step.

BACKUP VIDEO

"Thread Therapy with Dr. Bob" Cotton Staples & Fiber Explained

Superior Threads · 5:54

<https://www.youtube.com/watch?v=icwjSEvxd54>

A thread maker explains how staple length affects cotton thread quality and lint.

KEY TERMS

singles

A yarn of one strand of twisted fibers.

plied yarn

Two or more singles twisted together, usually in the opposite direction from their own twist; 2-ply, 3-ply and so on.

balanced yarn

A plied yarn whose ply twist cancels the singles' twist so it hangs in a loop without kinking.

cabled yarn

Plied yarns plied again, as in heavy cords and some threads.

core-spun thread

A thread with a continuous polyester filament core wrapped in cotton or polyester staple, combining strength with a soft surface.

tenacity

Breaking strength per unit of linear density, such as grams per denier or centinewtons per tex; it compares strength fairly across yarn sizes.

CORE IDEAS

The story. “A threefold cord is not quickly broken,” says the Preacher in Ecclesiastes, and every ropemaker knew it. In long ropewalks, workers twisted yarns into strands and strands into rope, each stage twisted against the last so the rope locked together. The same principle governs the thread in your sewing machine. In the 1800s, thread makers like the Coats and Clark families of Paisley, Scotland, built huge businesses on cotton sewing thread strong and smooth enough for the new machines; six-cord cotton, mercerized cotton, and later polyester and core-spun threads followed as machines grew faster.

How they figured it out. A singles yarn is lively: its twist wants to unwind, so it kinks and the fabric made from it may slant. Twisting two Z singles together with S twist balances them: as the ply twist goes in, the singles' twist partly untwists and the pair settles into a stable, round, stronger yarn. Spinners test balance by letting a loop hang free; a balanced yarn hangs straight, an unbalanced one twists back on itself. Plying also evens out thick and thin spots, since a thin place in one singles rarely lines up with a thin place in

the other. Novelty yarns break these rules on purpose: slub yarns keep thick spots for texture, bouclé plies one strand at a different speed so it forms loops, and chenille traps short cut tufts between two fine core yarns for a velvety pile.

The fabric science. Sewing thread is a working yarn: it must be strong, smooth, even and uniform so it can pass through the needle's eye thousands of times a minute and lock into a stitch. Cotton thread, usually mercerized, is soft, takes a hot iron and dyes well, but is weaker and less stretchy. Spun polyester thread is strong, has a little give for knits, and resists rot and abrasion. Core-spun thread wraps polyester filament in staple fiber, so it is strong and sews smoothly with little lint. Heavy-duty and upholstery threads are bonded nylon or polyester. Thread size is shown by a tex number (all-purpose thread is often about 25–30 tex) or by a “weight” number, the kilometers of thread in 1 kilogram, so 50 weight is finer than 40 weight.

Choosing thread. Match the thread to the fabric's fiber and stretch and to the job. Cotton thread on cotton quilts and heirloom work, where a seam should break before the cloth tears; polyester or core-spun on knits, synthetics and most garments; heavy-duty or bonded thread for denim, canvas and upholstery. A thread much stronger than the fabric can cut it under strain; a thread much weaker lets seams fail. Tenacity, strength per size, lets you compare threads fairly.

The studio lab. You will ply two strands of your handspun into a balanced 2-ply and test its balance. Then you will break one, two and three plies of a commercial yarn and several sewing threads with the bucket rig, calculating tenacity, to see whether a threefold cord really is three times as strong.

PICTURE STUDY



The Ropewalk in Edam, Max Liebermann, 1904 · Oil on panel · The Metropolitan Museum of Art, New York

Image: [Wikimedia Commons](#), public domain

Along a long, straight ropewalk under the trees in the Dutch town of Edam, ropemakers walk backward, paying out fiber from bundles at their waists while a wheel at the far end twists the yarn. Strand by strand, then strand against strand, they built the rope that rigged ships.

Look closely

- Follow the long lines of yarn. Where is the wheel that twists them?
- Find a ropemaker walking backward. Where is the fiber he is feeding into the twist?
- Look at the length of the path. Why does a ropewalk need to be so long?
- Notice the light. How does Liebermann use it to lead your eye down the walk?

Talk about it

1. Rope is made of yarns twisted into strands, and strands twisted the other way into rope. Why must each stage reverse the twist?
2. How is this work like plying your handspun?
3. Read Ecclesiastes 4:12 again. Why would every ropemaker agree with it?

Safety first. Keep feet clear of the bucket and clip threads firmly; thin threads snap suddenly. When plying on a spindle, keep the spindle shaft away from faces. Count pins and needles at the end of the session.

STUDIO LAB

A Threefold Cord: Plying and Thread Strength

Question: Is a plied yarn as strong as the sum of its plies, and which sewing thread is strongest for its size? You will ply your handspun, test its balance, then break plies and threads and calculate tenacity.

You will need

- Your handspun singles (or two balls of the same commercial singles), and your spindle
- A 3-ply commercial yarn that untwists easily into plies
- Three sewing threads: cotton (mercerized), spun polyester all-purpose and a heavy-duty or core-spun thread
- The bucket rig, the scale and your Lesson 4.4 tex table

Steps

1. **Hypothesis.** Predict the strength of a 3-ply yarn compared with one ply, and rank the three threads by tenacity.
2. **Ply.** Wind your singles into a two-strand ball (or use two balls). Ply them on the spindle by spinning it counterclockwise (S), letting the two strands twist together, then wind on. Ply 3 yards.
3. **Balance test.** Let a 12-inch loop of the plied yarn hang. Does it hang open, or twist? Compare with a loop of your singles.
4. **Ply strength.** Untwist the 3-ply yarn into single plies. Break five lengths each of one ply, two plies held together, and the intact 3-ply. Record the mean loads.
5. **Thread strength.** Break five 30-cm lengths of each sewing thread. Record means, and where each broke.
6. Using your tex measurements, calculate each thread's tenacity in g/den and cN/tex.
7. **Conclude.** How close was the 3-ply to three times one ply? Which thread was strongest overall and which per unit size?
8. **Repeat round.** Ply a second sample with more ply twist (spin longer before winding on) and test balance again. Can you find the twist that hangs perfectly?

Tips

- A balanced 2-ply forms an open loop with the plies lying neatly; an overplied one twists the other way.
- Sewing threads may outlast your bucket. Break two threads together or use a smaller-gauge thread if needed, and divide.
- Write the thread's brand, fiber and label size beside each result.

Check your work

- ☐ I plied and balance-tested my handspun.
- ☐ I compared one, two and three plies and calculated the ratio to the sum.
- ☐ I calculated tenacity for three threads and recommended a use for each.

LAB NOTEBOOK

1. Draw a Z singles, an S-ply 2-ply and a cabled yarn, with twist directions marked at each level.
2. Tape in your handspun singles and plied yarn, each with its balance-loop result.
3. Make a thread-choice chart: fabric or job, best thread, and why.

KEY FORMULAS

$$\text{tenacity (g/den)} = \frac{\text{breaking load (g)}}{\text{denier}}, \quad 1 \text{ g/den} \approx 8.83 \text{ cN/tex}$$
$$\text{tenacity (g/den)} = \text{denier} \times \text{breaking load (g)}, \quad 1 \text{ g/den} \approx 8.83 \text{ cN/tex}$$
$$\text{tex of plied yarn} \approx \text{number of plies} \times \text{tex of singles}$$
$$\text{tex of plied yarn} \approx \text{number of plies} \times \text{tex of singles}$$

From history. Sewing machines transformed thread. Early cotton thread was three-ply and too weak and uneven for fast machines, so makers developed six-cord thread, three 2-ply yarns plied together, smooth and strong enough for a lockstitch. For a century “six-cord” printed on a spool meant thread a machine could trust.

WORKED EXAMPLES

Example 1. A polyester thread of 30 tex breaks at a mean load of 1,620 g. Find its denier and its tenacity in g/den and cN/tex.

Show solution

1. Denier: $9 \times 30 = 270$ den $9 \times 30 = 270$ den.
2. Tenacity: $\frac{1,620 \text{ g}}{270 \text{ den}} = 6.0 \text{ g/den}$ $270 \text{ den} \times 6.0 \text{ g/den} = 1,620 \text{ g}$; $6.0 \times 8.83 \approx 53 \text{ cN/tex}$ $6.0 \times 8.83 \approx 53 \text{ cN/tex}$.

Answer: 6.0 g/den (about 53 cN/tex). A cotton thread of the same size might test near 3 g/den.

Example 2. One ply of a 3-ply yarn breaks at 820 g, two plies together at 1,560 g, and the full 3-ply at 2,450 g. What percent of the “three times one ply” value does the 3-ply reach?

Show solution

1. Three times one ply: $3 \times 820 = 2,460$ g $3 \times 820 = 2,460$ g.
2. Percent: $\frac{2,450}{2,460} \times 100\% = 99.6\%$ $2,460 \times 99.6\% = 2,450$ g $2,450 \times 100\% = 99.6\%$.

Answer: Almost exactly three times as strong. Plying also makes it more even, so it seldom breaks at a weak spot.

Example 3. A thread is labeled 50 weight (50 km per kg). Find its tex and denier, and the meters in a 100 g cone.

Show solution

1. 50 km per 1,000 g means $\frac{1,000 \text{ g}}{50 \text{ km}} = 20 \text{ tex}$ $50 \text{ km} \times 20 \text{ tex} = 1,000 \text{ g}$; denier 180 180 .
2. Length: $\frac{100 \text{ g}}{20 \text{ g/km}} = 5 \text{ km} = 5,000 \text{ m}$ $20 \text{ g/km} \times 5 \text{ km} = 100 \text{ g}$ $5 \text{ km} = 5,000 \text{ m}$.

Answer: 20 tex (180 denier); about 5,000 m on a 100 g cone.

PRACTICE

1. **Easy** What is a balanced yarn, and how can you test for it?

Show answer

A plied yarn whose ply twist cancels the singles' liveliness; let a loop hang: a balanced yarn hangs without twisting on itself.

2. **Easy** If singles are spun Z, which direction are they usually plied?

Show answer

S.

3. **Easy** Describe how bouclé and chenille yarns are made.

Show answer

Bouclé: one strand plied at a faster rate so it forms loops. Chenille: short cut tufts trapped between two twisted core yarns.

4. **Medium** A 2-ply yarn is made of two 18-tex singles. Estimate its tex.

Show answer

About 36 tex (slightly more because plying shortens the length).

5. **Medium** A 25-tex thread breaks at 900 g. Find its tenacity in g/den.

Show answer

$900/225 = 4.0 \text{ g/den}$ $900/225 = 4.0 \text{ g/den}$

6. **Medium** Why might a quilter choose cotton thread for a cotton quilt?

Show answer

It matches the fabric's strength and shrinkage, takes a hot iron, and if stressed the seam thread breaks before the cloth tears.

7. **Medium** Which thread would you choose for a knit T-shirt, and why?

Show answer

Polyester or core-spun all-purpose thread, which is strong and has a little give so seams stretch with the knit.

8. **Hard** Convert a 40-weight thread to tex and find the length on a 250 g cone.

Show answer

25 tex; $250/25 = 10$ km $250/25 = 10$ km.

9. **Hard** A thread of 270 denier and tenacity 5.5 g/den is used in a seam with 12 stitches per inch, each stitch using two thread segments across the seam line. Estimate the load needed to break the stitches in 1 inch of seam, ignoring the fabric.

Show answer

Each thread: $270 \times 5.5 = 1,485$ g $270 \times 5.5 = 1,485$ g; $12 \times 2 \times 1,485 \approx 35,600$ g $12 \times 2 \times 1,485 \approx 35,600$ g, about 36 kg, so the fabric usually fails first.

10. **Hard** Why should upholstery not be sewn with all-purpose cotton thread?

Show answer

Upholstery seams take heavy strain and abrasion; cotton all-purpose thread is too weak and wears through. Use bonded nylon or polyester.

11. **Challenge** Ecclesiastes 4:12 speaks of a threefold cord. Using your lab data, explain both the arithmetic (strength adds) and the reason plied cords are even more reliable than three loose strands.

Show answer

Plied strength is close to the sum of the plies. But twisted together, the plies support each other at weak spots and share load evenly, so a plied cord rarely fails at one flaw, while three loose strands can each break separately at their weakest point. Together they are "not quickly broken."

COMMON MISTAKES

- Plying in the same direction as the singles. The yarn overtwists and kinks; ply opposite.
- Using the strongest possible thread everywhere. Thread far stronger than the fabric can cut it at the seam under strain.
- Comparing thread strength without size. Use tenacity.

Make it a game · Threefold Tug. Each player gets one strand of cheap yarn. Players pull to see who can break it with their hands (gloves on). Then twist three strands together and try again. Then six. Record how many people are needed to break each, and finish by reciting Ecclesiastes 4:12 together.

Scripture. "And if one prevail against him, two shall withstand him; and a threefold cord is not quickly broken." (Ecclesiastes 4:12, KJV)

The Preacher's picture of friendship comes straight from the ropewalk. Strands twisted together share the load and cover each other's weak spots, which is exactly what your plying lab measures.

UNIT 4 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **7 pts**
Explain how twist holds a staple yarn together and why strength peaks at an optimum twist.
2. **7 pts**
You count 21 turns in 3 in of a 0.06-in yarn. Find the TPI and the twist angle.
3. **7 pts**
Compare the drop spindle, the great wheel and the flyer wheel.
4. **7 pts**
Describe the jenny, water frame and mule (inventor, date, how each worked, what yarn it made).
5. **7 pts**
A spindle turns 3,000 times a minute spinning 20 TPI yarn. Find the delivery per minute and yards per 10-hour day.
6. **7 pts**
Tell the story of Samuel Slater and the Pawtucket mill in three or four sentences.
7. **7 pts**
Describe the work and life of the Lowell mill girls honestly, including one way they sought better conditions.
8. **7 pts**
Who was Lewis Hine, and what did his photographs help accomplish?
9. **6 pts**
A skein of 60 yd weighs 28 g. Find its grist and its tex.
10. **7 pts**
Convert Ne 30 to tex, denier and metric count.
11. **6 pts**
Explain the difference between direct and indirect count systems with one example of each.
12. **6 pts**
What is a balanced yarn, and why are singles usually plied in the opposite direction?
13. **6 pts**
A 27-tex thread breaks at 1,215 g. Find its tenacity in g/den and cN/tex.
14. **6 pts**
Choose a thread for (a) a denim work apron, (b) a cotton quilt, (c) a polyester knit shirt, with a reason each.
15. **7 pts**
Short essay (5–7 sentences): The spinning machines of 1764–1800 have been called both a blessing and a curse. Using facts from this unit, write a balanced answer.

UNIT PROJECT: A HANDSPUN SKEIN AND A YARN REPORT

Spin, ply and finish a skein of at least 20 yards of balanced 2-ply handspun yarn. Wash it, dry it under light tension, and tag it with its yardage, weight, grist, tex, TPI of singles and ply, and its Craft Yarn Council weight class.

Write a two-page yarn report: your twist-and-strength graph with the optimum marked, your ply-strength and thread tenacity results, and a one-paragraph history of how your skein would have been made in 1700, 1800 and today.

LOOK FOR	WHAT IT MEANS
Skein quality	The skein is continuous, plied in the opposite direction, hangs balanced, and is reasonably even for a beginner.
Measurements and math	Yardage, weight, grist, tex and TPI are measured carefully and calculated correctly with units.
Lab results	The twist-and-strength graph and the thread data are complete and honestly interpreted.
History	The history paragraph is accurate and fair to both the gains and the costs of mechanization.
Records and improvement	The notebook shows practice rounds and what changed between first and final yarn.

ANSWER KEY

1. Twist wraps fibers in helices that squeeze together under tension, so friction holds them. Beyond the optimum, fibers tilt so far from the axis that less of their strength pulls along the yarn, and strength falls.
2. 7 TPI; $\tan\theta = \pi(0.06)(7) = 1.32$; $\tan\theta = 1.32$, $\theta \approx 53^\circ$
3. Spindle: hand-flicked, twist and wind in turns, portable. Great wheel: a big drive wheel turns the spindle fast, but the spinner stops to wind on. Flyer wheel: flyer and bobbin twist and wind continuously, often treadled, freeing both hands.
4. Hargreaves's jenny (c. 1764): many spindles and a moving carriage, soft weft yarn. Arkwright's water frame (1769): roller drafting, water power, strong warp. Crompton's mule (1779): rollers plus carriage, fine strong even yarn.
5. 150 in/min; $150 \times 600 = 90,000$ in = 2,500 yd
6. Slater apprenticed under Jedediah Strutt, Arkwright's partner, and memorized the machinery. Britain forbade skilled mill workers to leave, but he sailed to America in 1789. With Almy and Brown of Providence he rebuilt the machines and began water-powered spinning at Pawtucket in 1790, building Slater Mill in 1793; his first workers were children.
7. Young New England farm women lived in company boarding houses and earned cash wages, but worked about 12–13 hours a day, six days a week, in hot, noisy, dusty rooms. They walked out over wage cuts and petitioned for a ten-hour day.
8. A photographer for the National Child Labor Committee (1908–1917) who documented child workers in mills and elsewhere; his pictures helped win state laws and, in 1938, the Fair Labor Standards Act's limits on child labor.
9. $60 \times 453.6/28 \approx 972$ yd/lb; $60 \times 453.6/28 \approx 972$ yd/lb; $496,055/972 \approx 510$ tex
10. 19.7 tex; 177 denier; Nm 50.8.
11. Direct: weight per fixed length, larger is heavier (tex, denier). Indirect: length per fixed weight, larger is finer (cotton count, metric count).
12. A plied yarn that hangs without twisting on itself; opposite ply twist cancels the singles' liveliness so the yarn is stable and round.
13. Denier 243; $1,215/243 = 5.0$ g/den ≈ 44 cN/tex
14. (a) Heavy-duty polyester or core-spun: strength for thick seams. (b) Cotton: matches the fabric and lets thread fail before cloth. (c) All-purpose polyester or core-spun: strength with give.
15. A strong essay cites cheaper cloth, enormous gains in output (one frame equaling hundreds of spinners), new jobs and later prosperity, against lost cottage income, long hours, dust and danger, and child labor; it notes reformers, Hine and the 1938 law, and concludes with a reasoned judgment.

FABRIC CONSTRUCTION

Yarn becomes cloth in a few basic ways. It can be woven, two sets of yarns interlaced at right angles on a loom; knitted, one yarn looped through loops; or skipped altogether, with fibers matted, bonded or tangled directly into felt and nonwovens. Lace, the most delicate of all, is built by twisting and crossing threads around pins or by looping with a needle. Each construction gives a fabric its own character: woven cloth is stable and frays, knits stretch and run, nonwovens neither fray nor drape.

This unit teaches you to read any fabric like a textile engineer. You will weave plain, basket and rib samplers; learn twill and satin; take apart a fabric under the linen tester to find its weave, warp, ends and picks per inch and weight in grams per square meter; meet Jacquard's punched cards and the truth about thread count; knit and measure rib and jersey; and try your hand at bobbin lace while Vermeer's lacemaker looks on. The unit project is a fabric-analysis notebook that will serve you every time you shop for cloth.

PREREQUISITES

- Unit 4: twist, ply and tex
- The 10× magnifier or linen tester, the 0.1 g scale and a clear ruler
- Knitting needles (US 8 / 5 mm) and a ball of worsted-weight yarn; a crochet hook helps for fixing

MASTERY CHECKLIST

- ☐ I can identify warp and weft, face and back, and plain, twill and satin weaves and their variations on real fabric.
- ☐ I can measure ends and picks per inch, thread count and fabric weight in g/m² and oz/yd², and explain what thread count does and does not tell you.
- ☐ I can tell the story of Jacquard's punched cards and their link to computing.
- ☐ I can distinguish weft knits and warp knits, courses and wales, jersey, rib and interlock, and measure stitch density and stretch.
- ☐ I can describe felt, needle-punched, spunbond and spunlace nonwovens and needle, bobbin and machine lace.
- ☐ I can calculate yarn needed for a woven or knitted piece.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **A 1-inch linen tester (pick glass):** The folding magnifier with a 1-inch window used throughout this unit; a few dollars at fabric and hobby stores.
- **A frame loom or a sturdy cardboard loom:** A 10 × 14 in picture frame with nails, or a heavy corrugated board with notches, is enough for Lesson 5.1's samplers.
- **Bobbin-lace starter supplies:** Optional. Lace bobbins, a foam lace pillow and pins are sold as kits; clothespins, a foam board and dressmaker pins work for Lesson 5.5's first braid.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

5.1	The Loom: Warp, Weft and Plain Weave	3 sessions of 50 minutes
5.2	Twill, Satin and Fabric Analysis	3 sessions of 50 minutes
5.3	Jacquard's Cards and the Truth About Thread Count	3 sessions of 50 minutes
5.4	William Lee's Frame and the Knit Loop	3 sessions of 50 minutes
5.5	Felt, Nonwovens and Lace	3 sessions of 50 minutes

5.1 THE LOOM: WARP, WEFT AND PLAIN WEAVE

OBJECTIVES

- Name the parts and motions of a loom (warp, weft, heddles, shed, pick, beat, reed) and describe how weaving works.
- Weave plain, basket and rib samplers and explain how each structure changes the fabric.
- Calculate warp length, take-up and yarn needed for a woven piece.

Warm-up. Hold a handkerchief, a cotton sheet or a dish towel up to a window and look through it with your magnifier. Find the threads running lengthwise and crosswise. Count how many go over and under before they switch.

WATCH

Weaving on Mount Vernon's 18th-Century Loom

[George Washington's Mount Vernon](#) · 3:46

<https://www.youtube.com/watch?v=FnbUF0wglfw>

WHEN TO WATCH

After “How they figured it out.” Name each motion as the weaver makes it: open the shed, throw the shuttle, beat.

BACKUP VIDEO

18th-Century Weaving at Colonial Williamsburg

[Colonial Williamsburg](#) · 3:05

<https://www.youtube.com/watch?v=Vtz2Y8h5eLY>

Colonial Williamsburg's weavers explain the household and shop weaving of the 1700s; compare their loom with Mount Vernon's.

KEY TERMS

warp

The lengthwise yarns held under tension on the loom; also called ends.

shed

The opening made when some warp ends are raised and others lowered, through which the weft passes.

reed and beating

The reed is a comb that spaces the warp; beating presses each new pick against the woven cloth.

weft

The crosswise yarns passed through the warp; each pass is a pick. Also called filling.

heddle and harness

A heddle is a cord or wire with an eye that lifts one warp end; a harness (shaft) holds many heddles that rise together.

plain weave

The simplest weave: each weft goes over one warp and under the next, alternating every pick. Basket weave and rib weave are its variations.

CORE IDEAS

The story. Weaving is one of the oldest crafts in the world, and Scripture is woven through with it: the fine twined linen of the tabernacle, Delilah's loom, the weaver's shuttle that Job says is swifter than his days. When the soldiers divided Christ's garments at the cross, they did not tear his coat, for it “was without seam, woven from the top throughout,” a single piece made on the loom with great skill. For thousands of years most cloth was woven at home or in small workshops on looms that people built themselves.

How they figured it out. Every loom solves the same problem: holding hundreds of warp ends parallel and taut while lifting some and lowering others, quickly, for every pass of the weft. The ancient warp-weighted loom hung its warp from a beam with stone weights at the bottom. The floor loom, common in Europe by the Middle Ages, wound the warp on a back beam, passed each end through a heddle on one of several harnesses, and let the weaver raise harnesses with foot treadles, leaving both hands free to throw the shuttle and pull the beater. Its three motions, shed, pick and beat, repeat thousands of times in every yard.

The fabric science. In plain weave each yarn interlaces as often as possible, which makes a firm, stable fabric that frays only slowly and looks the same on both sides: muslin, percale, broadcloth, canvas and voile are all plain weaves. Changing the yarns changes the

fabric: thick weft over fine warp makes a rib (poplin, taffeta); two ends and two picks working together make basket weave (oxford cloth, monk's cloth). A fabric with equal ends and picks per inch of equal yarns is *balanced*. Because warp and weft bend over and under each other, each yarn is longer than the cloth it makes; that extra length is *take-up* (or crimp), usually a few percent, and weavers must allow for it.

Grain. Warp threads run parallel to the selvages, the finished edges where the weft turns back. The warp direction is the lengthwise grain: the most stable direction, usually with the strongest, most twisted yarns. Weft runs on the crosswise grain, with a little more give. The diagonal, the bias, stretches most of all. Every pattern piece you cut in Units 8–10 will be laid on the grain.

The studio lab. You will warp a frame or cardboard loom and weave three samplers, plain, basket and rib, measuring ends and picks per inch and take-up on each. A weaver's warp calculation will tell you how much yarn to buy before you begin.

PICTURE STUDY



Weaver, Vincent van Gogh, 1884 · Oil on canvas · Image from Wikimedia Commons (Google Art Project), public domain
Image: [Wikimedia Commons](#), public domain

In 1884, in the Dutch village of Nuenen, van Gogh painted the weavers who worked at home on huge wooden handlooms that filled their small cottages. He painted the loom almost as a cage of beams around the weaver, who worked long hours for little pay as factory cloth undercut hand weaving.

Look closely

- Find the warp. Where does it come from, and where is the woven cloth wound?
- Find the weaver's hands and feet. Which motion is he making: shedding, picking or beating?
- Look for the beater or reed. How far does it swing?
- Count the heavy beams of the loom frame. Why must a loom be so strong?

Talk about it

1. Van Gogh said he admired these weavers. What in the painting shows respect for their work?
2. A hand weaver in 1884 competed with power looms like those at Lowell. Using Lesson 4.3, how did his output compare?
3. What would you need to know to calculate how many days this weaver needed for one bolt of cloth?

Safety first. Hammer nails for a frame loom with a parent's help, wearing safety glasses, and cover sharp points with tape. Carry scissors closed and points down. Count pins and needles at the end of the session.

Three Samplers on a Frame Loom

Question: How do plain, basket and rib weaves differ in thickness, stability and appearance when woven from the same yarn? You will build or borrow a loom, weave three samplers and measure them.

You will need

- A frame loom or a heavy cardboard loom about 10 × 14 in
- Worsted-weight cotton or wool yarn in two colors, and a thicker yarn for the rib sampler
- A large blunt tapestry needle or a craft-stick shuttle, a fork or wide comb for beating, a ruler and the linen tester

THREE-STRUCTURE WOVEN SAMPLER

Finished size: One strip about 6 in wide and 12 in long with three 3–4 in sections · About 2 hours

Fabric and notions

- About 60 yd of worsted-weight cotton yarn for warp and weft
- About 15 yd of a contrasting or thicker yarn for the rib section
- A frame or cardboard loom with notches or nails at ¼-in spacing (4 EPI) or ⅛-in spacing (8 EPI)

How to make it

1. Warp the loom: tie the yarn at one corner and wrap it around the notches top to bottom, back and forth, 24–48 ends across 6 in. Keep even, firm tension. Tie off.
2. Weave a 1-in header of plain weave with scrap yarn, beating it firmly, to space the warp.
3. Plain weave: pass the weft over one end and under the next; on the return pick, reverse. Leave the weft in an arc (a “bubble”) before beating so the edges do not draw in. Weave 3 in.
4. Basket weave: treat pairs of ends as one and lay two picks in each shed. Weave 3 in.
5. Rib weave: alternate a thick pick and a thin pick in plain weave, beating the thick ones well. Weave 3 in.
6. Weave a 1-in plain-weave footer, then cut the warp off the loom two ends at a time and tie each pair in an overhand knot against the cloth.
7. Wash the sampler gently, dry it flat and trim the fringe evenly.

Fabric check: Smooth, non-stretchy cotton or wool yarn is easiest; avoid fuzzy mohair, slippery rayon and stretchy acrylic for the warp. A thicker cotton string makes a good rib weft. Wool-sensitive students can use all cotton.

Steps

1. **Hypothesis.** Predict which section will be thickest, which will draw in most at the edges, and which will fray fastest.
2. Weave the sampler following the pattern card.
3. Before cutting off the loom, measure the width at the start and end of each section to find draw-in.
4. After finishing, count EPI and PPI in each section with the linen tester, and measure each section's thickness by folding it and measuring a stack of four layers.
5. Pull out one warp end and one weft pick from the plain section, straighten them and calculate take-up.
6. Snip a ½-in slit in a scrap corner of each section and rub it 20 times with your thumb. Which frays most?
7. **Conclude.** Rank the weaves for thickness, stability and fraying, and explain each with interlacing.
8. **Repeat round.** Weave one more inch of plain weave beating much harder, and one beating lightly. How do PPI and feel change?

Tips

- Draw-in, the edges creeping inward, comes from pulling the weft too tight. Leave it in a gentle arc before beating.
- Older students: try a 2/2 twill section on the same warp as a preview of Lesson 5.2.
- Your loom's notch spacing sets your EPI; your beating sets your PPI.

Check your work

- ☐ I wove three sections of distinct structure with even edges.
- ☐ I measured EPI, PPI, draw-in, thickness and take-up and recorded them in a table.
- ☐ I explained the differences using interlacing.

LAB NOTEBOOK

1. Draw a labeled floor loom: warp beam, heddles, harnesses, treadles, reed and beater, shuttle, cloth beam.
2. Draw weave diagrams on graph paper (filled square = warp up) for plain, basket and rib.
3. Tape in your sampler or a photo of it with its measurements.

KEY FORMULAS

$$\begin{aligned} \text{warp length} &= \text{finished length} + \text{take-up} + \text{loom waste} \\ \text{warp length} &= \text{finished length} + \text{take-up} + \text{loom waste} \\ \text{number of warp ends} &= \text{EPI} \times \text{width in the reed} \\ \text{number of warp ends} &= \text{EPI} \times \text{width in the reed} \\ \text{weft needed} &\approx \text{PPI} \times \text{woven length} \times \text{width} \times (1 + \text{take-up}) \\ \text{weft needed} &\approx \text{PPI} \times \text{woven length} \times \text{width} \times (1 + \text{take-up}) \end{aligned}$$

From history. Edmund Cartwright, an English clergyman, patented a power loom in 1785 after hearing it said that weaving could never be mechanized. His first machine was clumsy, but improved power looms spread through British and American mills in the early 1800s, and by mid-century hand weavers like van Gogh's neighbors could no longer compete on price.

WORKED EXAMPLES

Example 1. A weaver wants a table runner 14 in wide and 60 in long finished, at 12 EPI, with 10% take-up and shrinkage and 27 in of loom waste. Find the number of warp ends, the warp length, and the total warp yarn in yards.

Show solution

1. Ends: $12 \times 14 = 168$ ends
2. Warp length: $60 \times 1.10 + 27 = 93$ in
3. Total: $168 \times 93 \text{ in} = 15,624 \text{ in} \approx 434 \text{ yd}$

Answer: 168 ends, each 93 in long; about 434 yd of warp yarn.

Example 2. The same runner is woven at 12 PPI. Estimate the weft yarn needed, allowing 10% for take-up.

Show solution

1. Picks: $12 \text{ PPI} \times 60 \text{ in} \times 1.10 = 792$ picks
2. Each pick crosses 14 in plus take-up: $14 \times 1.10 = 15.4$ in
3. Weft: $792 \times 15.4 \text{ in} = 12,197 \text{ in} \approx 339 \text{ yd}$

Answer: About 340 yd of weft; with the warp, about 770 yd of yarn for one runner.

Example 3. A warp end measured 20.0 cm in the fabric is 21.3 cm long when pulled out and straightened. Find its take-up.

Show solution

1. take-up = $\frac{21.3 - 20.0}{20.0} \times 100\% = 6.5\%$

Answer: 6.5% take-up: every yard of cloth used about 1.065 yd of warp.

PRACTICE

1. **Easy** Which yarns run parallel to the selvage?
Show answer
The warp.
2. **Easy** Name the three basic motions of weaving.
Show answer
Shedding (opening the shed), picking (passing the weft), beating.
3. **Easy** Name two fabrics that are plain weave.
Show answer
Any two of muslin, percale, broadcloth, canvas, voile, poplin, taffeta.
4. **Medium** How many warp ends for a 20-in-wide scarf at 15 EPI?
Show answer
300.
5. **Medium** A 10.0 cm length of weft measures 10.4 cm straightened. Find its take-up.
Show answer
4%.
6. **Medium** Why does plain weave fray more slowly than a weave with long floats?
Show answer
Each yarn interlaces at every crossing, so friction and interlacing hold it in; long floats have few crossings to grip.
7. **Medium** What is the difference between rib weave and basket weave?
Show answer
Rib: one set of yarns is thicker or grouped, making ridges. Basket: two or more ends and picks work together as one, making a checkerboard.
8. **Hard** A towel 18 in wide by 30 in long is woven at 20 EPI with 12% take-up and 18 in of loom waste. Find the warp length and total warp yardage.
Show answer
 $30 \times 1.12 + 18 = 51.6$ in $30 \times 1.12 + 18 = 51.6$ in; $360 \text{ ends} \times 51.6 \text{ in} = 18,576 \text{ in} \approx 516 \text{ yd}$.
9. **Hard** A cone holds 1,680 yd. How many 2½-yard warp ends can you wind from it, and how wide a warp is that at 12 EPI?
Show answer
 672 ends ; $672/12 = 56$ in $672/12 = 56$ in.
10. **Hard** Why is the lengthwise grain the most stable direction in most woven fabric?
Show answer
Warp yarns are held taut on the loom, usually more tightly twisted and more numerous, so they stretch least; weft is laid in more loosely.
11. **Challenge** John 19:23 says Christ's coat was woven "from the top throughout," without seam. Using what you know of looms, describe one way a weaver could make a seamless tunic on a loom.
Show answer
For example, weave a double cloth (two layers joined at both edges) to form a tube, leaving openings for neck and arms; or weave to shape on a wide warp-weighted loom so the garment needs no sewing. Either requires careful planning of warp and shed.

COMMON MISTAKES

- Pulling the weft straight across. The edges draw in; leave a bubble before beating.
- Confusing warp and weft on a cut piece. Find the selvage, or pull a yarn of each and compare twist and straightness.

- Forgetting take-up and loom waste when buying yarn. The warp is always longer than the cloth.

Make it a game · Warp or Weft? A parent cuts small squares from five fabrics with no selvage. Each player gets 30 seconds per square to decide which direction is warp, using any clue: straightness, twist, count, stretch. One point per correct call, revealed by the parent's marked master pieces. Tie-breaker: identify the weave of each.

Scripture. “Then the soldiers, when they had crucified Jesus, took his garments, and made four parts, to every soldier a part; and also his coat: now the coat was without seam, woven from the top throughout.” (John 19:23, KJV)

The Gospel notices the weaving of a single garment, a coat made whole on the loom, at the very hour of the crucifixion. Good work matters, even to the soldiers who would not tear it.

5.2 TWILL, SATIN AND FABRIC ANALYSIS

OBJECTIVES

- Describe twill and satin weaves and their variations, and explain how floats and interlacing give each its character.
- Analyze a fabric: face and back, warp and weft, weave, ends and picks per inch, and fabric weight.
- Calculate fabric weight in g/m^2 and oz/yd^2 from a measured sample.

Warm-up. Look at the front and back of a pair of blue jeans with your magnifier. Which way do the diagonal lines run? Why is the inside lighter than the outside?

WATCH

The 3 Fundamental Textile Weaves: Plain, Twill and Satin

[Textile with Alberto](#) · 3:51

<https://www.youtube.com/watch?v=TYrQBcPBk3U>

WHEN TO WATCH

After “The fabric science.” Pause at each weave diagram and draw it in your notebook before the narrator explains it.

BACKUP VIDEO

FIT's Textile-Testing Lab

[Fashion Institute of Technology](#) · 1:20

<https://www.youtube.com/watch?v=QssaPcq2v7M>

A short tour of a college textile-testing lab: strength, abrasion and colorfastness machines at work.

KEY TERMS

twill weave

A weave in which each weft passes over two or more warps and the interlacings step over by one on each pick, forming diagonal lines (wales).

float

A length of yarn that passes over two or more yarns without interlacing.

fabric weight

Mass per area, in grams per square meter (g/m^2 , GSM) or ounces per square yard (oz/yd^2).

satin weave

A weave with long floats and interlacings spread out so they never touch, giving a smooth, lustrous face; when cotton weft floats form the face it is called sateen.

ends and picks per inch (EPI, PPI)

The number of warp yarns and weft yarns in one inch of fabric.

face and back

The right side and the wrong side of a fabric; in twills and satins they look different.

CORE IDEAS

The story. The skilled weavers of the tabernacle were “filled with wisdom of heart” to work as engravers, designers, embroiderers and weavers in blue, purple, scarlet and fine linen (Exodus 35:35). Weaving's great patterns, twills and damasks, come from the same few rules applied with wisdom. Denim, perhaps the most familiar twill on earth, takes its name from serge de Nîmes, a sturdy twill of the French town of Nîmes, and in the 1870s Levi Strauss and the tailor Jacob Davis riveted the pocket corners of denim work pants for miners and farmers, patenting the idea in 1873.

How they figured it out. In plain weave every yarn interlaces as often as possible. Weavers learned that letting yarns float over two, three or more neighbors before interlacing, and stepping the interlacings over one end at each pick, made a diagonal line: twill. Fewer interlacings let the yarns pack closer, so twills can be denser, heavier and more drapable than plain weaves of the same yarn, and they hide soil. Spreading the interlacings even farther apart, so none touch, gave satin: long smooth floats that reflect light like a mirror, at the cost of snagging and wear.

The fabric science. Twills are named by their float pattern: a 2/1 twill has warp over two, under one; denim is usually a 3/1 warp-faced right-hand twill, with indigo warp on the face and undyed weft showing on the back. Gabardine, serge, drill, chino and herringbone (a twill that reverses direction in stripes) are all twills. Satins have floats of four or more: a 4/1 or 7/1 satin. Satins and sateens are smooth and lustrous; percale (a plain weave) is crisp and cool. To analyze a fabric, find the selvage or test the yarns: warp is usually straighter, more tightly twisted and more numerous. Count EPI and PPI under the linen tester, identify the float pattern, and weigh a measured square to find its weight. Fabric weight tells you a great deal: about 100 g/m² is a light shirting, 200–300 g/m² a bottom-weight twill, and 400 g/m² or more a heavy canvas or coating.

Look closely. Twill lines that run up to the right, like the middle of a Z, are right-hand twills; up to the left, left-hand. Under 10× you can count the floats: follow one weft across and count how many warps it passes over before it dips under.

The studio lab. This is the unit's fabric-analysis lab. With the linen tester, a ruler and the gram scale you will fully analyze six fabrics, recording face and back, warp direction, weave, EPI and PPI, fiber (from labels or burn tests) and weight, the same report a mill's quality lab makes for every lot.

PICTURE STUDY



The Weaver, Cornelis Gerritsz. Decker, c. 1650s · Oil on panel · Image from Wikimedia Commons, public domain
Image: [Wikimedia Commons](#), public domain

Cornelis Decker of Haarlem painted weavers' workshops again and again. Haarlem was a linen-weaving and bleaching town, and its weavers worked in dim, timbered rooms at great wooden looms like this one.

Look closely

- Find the loom and the weaver. Where is the woven cloth, and where is the warp?
- Look for spare bobbins, a winder or a child helping. Who else worked in a weaving household?
- Notice the light from the window. Where is it strongest, and why would a weaver want it on the cloth?
- Look at the beams overhead and the floor. How do they compare with the loom in Lesson 5.1's painting?

Talk about it

1. Haarlem weavers often wove linen damask with patterns of twill and satin. What would a pattern weaver need that a plain weaver would not?
2. What would a cloth inspector, like the syndics in Unit 3, check on a length from this loom?
3. How might this weaver count picks per inch without a linen tester?

Safety first. Cut sample squares with a rotary cutter on a mat, blade closed every time it is set down, or with shears; cut away from your hand. Burn tests for unknown fibers follow the Unit 1 rules, with a parent beside you.

The Fabric-Analysis Lab

Question: What are the full construction specifications of six real fabrics? You will analyze each like a mill's quality lab and write a spec sheet.

You will need

- Six woven fabrics, at least one plain weave, one twill and one satin or sateen (denim, a dress shirt, a sheet, a lining, a canvas tote, a dish towel)
- The linen tester, a clear ruler, the 0.1 g scale and a rotary cutter, mat and ruler
- Your burn-test kit (with a parent) for any fabric without a label

Steps

1. **Hypothesis.** Before analyzing, guess each fabric's weave and weight class.
2. Find the selvage or decide the warp direction for each fabric, and mark it with an arrow.
3. Identify face and back and the weave; for twills, note the direction and float pattern.
4. Count EPI and PPI in three places with the linen tester and average them.
5. Cut a 10 × 10 cm square exactly (rotary cutter and ruler), weigh it to 0.01 g if possible, and calculate GSM and oz/yd².
6. Record fiber content from the label or a burn test with your parent.
7. Write a one-line spec for each, for example: "100% cotton, 3/1 RH twill, 72 × 46, 390 g/m²."
8. **Conclude.** How well did your guesses match? Which measurement was hardest to get accurately?
9. **Repeat round.** Re-cut and reweigh the lightest fabric using a 20 × 20 cm square. How much did the GSM change?

Tips

- For dense fabrics, count over ½ inch and double it, or use a needle to point along the threads as you count.
- Cut squares precisely; a 1 mm error on a 10 cm side changes the area by 2%.
- Keep the squares: they become the swatches in your unit project notebook.

Check your work

- ☐ I fully analyzed six fabrics, including at least one plain, one twill and one satin.
- ☐ I counted in three places and averaged, and calculated weight correctly.
- ☐ I wrote a clear spec line for each fabric.

LAB NOTEBOOK

1. Draw weave diagrams for 2/1 twill, 3/1 twill, 2/2 twill and a 5-end satin on graph paper.
2. Tape each analyzed square on its own page with its spec line.
3. Make a weight ladder from 50 to 500 g/m² and place each fabric on it.

KEY FORMULAS

$$\text{GSM} = \frac{\text{mass (g)}}{\text{area (m}^2\text{)}}, \quad 10 \text{ cm} \times 10 \text{ cm} = 0.01 \text{ m}^2$$

$$\text{GSM} = \text{area (m}^2\text{)} \text{mass (g)}, \quad 10 \text{ cm} \times 10 \text{ cm} = 0.01 \text{ m}^2$$

$$\text{oz/yd}^2 = \frac{\text{GSM}}{33.9}$$

$$\text{oz/yd}^2 = 33.9 \text{GSM}$$

From history. Denim's indigo warp and white weft came from the work clothes of the 1800s, and Levi Strauss & Co. and Jacob Davis received their patent for riveted work pants on May 20, 1873. Riveting the pocket corners, the point where pants tore first under heavy tools, was a simple fix that made them last.

WORKED EXAMPLES

Example 1. A 10.0×10.0 cm square of denim weighs 3.85 g. Find its weight in g/m^2 and oz/yd^2 .

Show solution

$$1. \text{ Area: } 0.100 \text{ m} \times 0.100 \text{ m} = 0.0100 \text{ m}^2$$

$$2. \text{ GSM} = \frac{3.85 \text{ g}}{0.0100 \text{ m}^2} = 385 \text{ g/m}^2$$

$$3. \frac{385}{33.9} = 11.4 \text{ oz/yd}^2$$

Answer: 385 g/m^2 , about 11.4 oz: a classic midweight jean denim.

Example 2. A 5×5 cm sample of shirting weighs 0.28 g. Find its GSM. How much does 2 yards of the 58-in-wide fabric weigh?

Show solution

$$1. \text{ GSM} = \frac{0.28}{0.0025} = 112 \text{ g/m}^2$$

$$2. \text{ Area of } 2 \text{ yd} \times 58 \text{ in: } 1.829 \text{ m} \times 1.473 \text{ m} = 2.694 \text{ m}^2$$

$$3. \text{ Mass: } 112 \times 2.694 \approx 302 \text{ g}$$

Answer: 112 g/m^2 (a light shirting); 2 yd weighs about 300 g.

Example 3. Design reasoning. A family wants work pants that resist wear and hide soil, and a lining that slides on easily. Choose a weave for each and justify it.

Show solution

1. Work pants: a dense 3/1 or 2/1 twill (denim, drill, chino) packs more yarn per inch, wears well, drapes better than canvas and hides dirt in its diagonal texture.
2. Lining: a satin or a smooth plain weave in a slippery filament (rayon, acetate or polyester) lets the garment slide over other clothes; its floats are protected inside the garment from snagging.

Answer: Twill for the pants, satin (or a smooth plain weave) for the lining, each chosen for the job its structure does best.

PRACTICE

1. Easy What makes the diagonal lines in twill?

Show answer

Floats whose interlacings step over by one end on each pick.

2. Easy Why is the back of denim lighter than the face?

Show answer

It is a warp-faced twill: indigo warp floats on the face, and the undyed weft shows more on the back.

3. Easy Convert 200 g/m^2 to oz/yd^2 .

Show answer

$$200/33.9 \approx 5.9 \text{ oz/yd}^2$$

4. Medium A 10×10 cm square weighs 2.10 g. Find its GSM.

Show answer

$$210 \text{ g/m}^2$$

5. Medium Convert 8 oz/yd^2 canvas to g/m^2 .

Show answer

$$8 \times 33.9 = 271 \text{ g/m}^2$$

6. **Medium** Give one advantage and one disadvantage of satin weave.

Show answer

Advantage: smooth, lustrous, drapes well. Disadvantage: long floats snag and wear.

7. **Medium** How can you tell warp from weft without a selvage? Give two clues.

Show answer

Warp is usually straighter, more tightly twisted, more numerous (higher count), and finer or stronger.

8. **Hard** A 15×15 cm twill sample weighs 6.30 g. Find its GSM and oz/yd², and classify its weight.

Show answer

$6.30/0.0225 = 280 \text{ g/m}^2 \approx 8.3 \text{ oz/yd}^2$; $6.30/0.0225 = 280 \text{ g/m}^2 \approx 8.3 \text{ oz/yd}^2$; a bottom-weight twill.

9. **Hard** A bolt of 45-in-wide quilting cotton at 140 g/m^2 holds 15 yd. Estimate its fabric mass in kg.

Show answer

Area $13.72 \text{ m} \times 1.143 \text{ m} \approx 15.7 \text{ m}^2$; $13.72 \text{ m} \times 1.143 \text{ m} \approx 15.7 \text{ m}^2$; $15.7 \times 140 \approx 2.2 \text{ kg}$; $15.7 \times 140 \approx 2.2 \text{ kg}$.

10. **Hard** Two fabrics have identical yarns and EPI/PPI; one is plain weave, one 2/2 twill. Which is likely thicker and softer, and why?

Show answer

The twill: fewer interlacings let yarns pack and move more freely, giving more drape and often more thickness and softness.

11. **Challenge** Describe the weave diagram for a 3/1 right-hand twill on a 4×4 grid, then for a 5-end satin on a 5×5 grid, and explain the difference in how the interlacings are placed.

Show answer

Twill: each row has warp up on three ends and down on one, and the down position steps one end to the right on each row, so the interlacings touch diagonally and form a line. Satin: each row has one interlacing, stepping two ends at a time (ends 1, 3, 5, 2, 4), so no two interlacings touch and the surface shows only long, smooth floats.

COMMON MISTAKES

- Counting EPI on the bias. Align the linen tester's edge with a single yarn.
- Weighing a carelessly cut square. Measure and cut exactly; small errors grow when you divide.
- Calling every shiny fabric satin. Satin is a weave, not a fiber; cotton, silk and polyester can all be woven as satin.

Make it a game · Spec Sheet Showdown. A parent hides four fabric scraps in envelopes. Each player draws one, has three minutes with the linen tester and ruler, and writes a spec line: weave, $\text{EPI} \times \text{PPI}$ and weight class. Score two points for the right weave, one for counts within 10%, one for the right weight class.

Scripture. “Them hath he filled with wisdom of heart, to work all manner of work, of the engraver, and of the cunning workman, and of the embroiderer, in blue, and in purple, in scarlet, and in fine linen, and of the weaver;” (Exodus 35:35, KJV)

Scripture calls the weaver's skill a gift of wisdom from God. Learning to read a cloth's structure is a small share in that same wisdom.

5.3 JACQUARD'S CARDS AND THE TRUTH ABOUT THREAD COUNT

OBJECTIVES

- Tell how Joseph-Marie Jacquard's punched-card loom worked and how it influenced computing.
- Define thread count, explain how plied yarns can inflate it, and judge sheets by fiber, yarn, weave and weight as well as count.
- Count threads in several fabrics and calculate thread count, ply-adjusted count and pattern combinations.

Warm-up. Find a set of sheets in the house with a label. What thread count does it claim? Count the threads in a ½-inch square with your linen tester and double it. Does your count match?

WATCH

Binary and the Jacquard Mechanism - demonstration

Macclesfield Museums · 5:35

<https://www.youtube.com/watch?v=pzYucg3Tmho>

WHEN TO WATCH

After “How they figured it out.” Watch a card pass the needles: holes lift hooks, blank spots do not.

BACKUP VIDEO

How an 1803 Jacquard Loom Led to Computer Technology

The Henry Ford · 1:57

<https://www.youtube.com/watch?v=MQzpLLhN0fY>

A short museum explanation of how Jacquard's loom led to computing.

KEY TERMS

Jacquard mechanism

A device on top of a loom that lifts each warp end separately according to holes punched in a chain of cards, allowing any woven pattern.

damask and brocade

Patterned fabrics woven on Jacquard (or older draw) looms: damask is reversible, with satin and sateen figures; brocade adds extra weft patterns.

ply-inflated count

A thread count that counts each ply of a plied yarn separately, making the number larger than the yarns actually present.

punched card

A card whose holes encode instructions: here, which warp ends rise for one pick.

thread count

The number of warp and weft yarns in one square inch of fabric (EPI + PPI).

percale and sateen

Two common sheet constructions: percale is a crisp plain weave (at least 180 count); sateen is a smooth, lustrous satin-type weave.

CORE IDEAS

The story. In the silk-weaving city of Lyon, France, patterned silks were woven on draw looms, where a helper, often a child called a drawboy, perched above the loom pulling cords to lift the warp ends for each pick, by memory and by a written plan. Joseph-Marie Jacquard, a Lyon weaver's son, set out to replace the drawboy. Building on earlier attempts by Basile Bouchon and Jacques Vaucanson, he showed his loom attachment in the early 1800s and perfected it by 1804. A chain of stiff punched cards passed over a set of needles: where a card had a hole, a needle slid through and its hook lifted a warp end; where it had none, the end stayed down. One card per pick; any pattern the cards could hold, the loom could weave.

How they figured it out. Lyon's weavers at first feared the machine would take their work, and some resisted it. But the Jacquard loom spread through France and the world, and patterned silks, damask linens and later woven upholstery became far cheaper. Its idea outlived the silk trade: Charles Babbage planned to feed his Analytical Engine with punched cards in the 1830s, and Ada

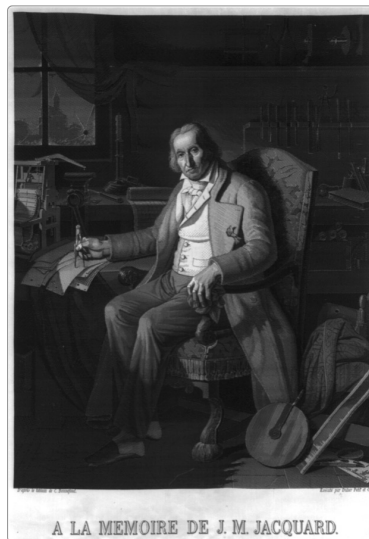
Lovelace wrote in 1843 that it would weave “algebraical patterns just as the Jacquard-loom weaves flowers and leaves.” Herman Hollerith's punched cards tabulated the 1890 U.S. census, and punched cards fed computers into the 1970s. In 1839 Lyon weavers wove a portrait of Jacquard in silk so fine it looks like an engraving, using about 24,000 cards.

The fabric science: thread count. Thread count is simply ends per inch plus picks per inch: a sheet with 100 EPI and 100 PPI has a thread count of 200. A higher count of the same yarn packs more yarn into the cloth, making it denser, smoother and more durable, up to a point. But some sellers use plied yarns, two or three fine singles twisted together, and count every ply, so a fabric with 200 actual yarns becomes “600 thread count.” In 2005 the Federal Trade Commission advised that counting plies that way could mislead buyers. The truth is that a sheet's quality depends on fiber (long-staple cotton is smoother and stronger), yarn (fine, combed, even, singles or two-ply), weave (percale crisp, sateen silky) and finish, with a true count in the range of roughly 200 to 400 for most good sheets.

Patterns as numbers. Each Jacquard card is a row of yes-or-no decisions: up or down. With n hooks, one card can encode 2^n different lift patterns, which is why the Jacquard loom is often called an ancestor of the binary computer.

The studio lab. You will count threads in sheets and other fabrics, untwist yarns to find plies, and compare true and label counts. Then you will design a small Jacquard pattern on graph paper and punch it as a chain of paper cards, weaving one row from each card on your frame loom.

PICTURE STUDY



To the Memory of J. M. Jacquard (woven portrait), Woven by Didier, Petit et Cie, after a painting by Claude Bonnefond, 1839 · Woven silk · Library of Congress (Prints and Photographs), and other collections

Image: [Wikimedia Commons](#), public domain

This is not an engraving. It is cloth: a portrait of Jacquard woven in black and white silk on a Jacquard loom in Lyon, with thousands of picks and about 24,000 punched cards. Charles Babbage owned a copy and loved to ask visitors how they thought it had been made.

Look closely

- Find Jacquard's tools on the table. Which parts of his loom can you see?
- Find the stack or chain of cards. How are they joined?
- Look closely at the shading on the face and hands. How can a weave show gray when it has only black and white yarns?
- Find the lettering. It too was woven, pick by pick.

Talk about it

1. If each card controlled one pick, what would a single wrongly punched hole do to the picture?
2. Babbage used this portrait to explain his engine. Why was it such a good example?
3. What does this cloth tell you about the patience of Lyon's card punchers and weavers?

Safety first. Use a single-hole punch or a pencil point on a foam pad to punch paper cards, keeping fingers clear of the punch. Carry scissors closed and points down. Count pins and needles at the end of the session.

STUDIO LAB

Count the Threads, Punch the Cards

Question: Do sheet labels report the true thread count, and how does a punched-card program become a woven pattern? You will count threads and plies in several fabrics, then weave a small card-programmed pattern.

You will need

- Two or three sheets or pillowcases with labeled thread counts (including at least one above 400 if available), plus a dress shirt and a handkerchief
- The linen tester, a needle for pointing and untwisting, and a calculator
- Graph paper, index cards cut into 1 × 4 in strips, a hole punch, yarn and the frame loom from Lesson 5.1 (re-warped with 8 ends)

Steps

1. **Hypothesis.** Predict which labeled counts will match your count and which will be inflated.
2. For each fabric, count ends and picks over $\frac{1}{2}$ in in three places and average. Calculate the thread count.
3. Pull one warp and one weft yarn from a hem or seam allowance and untwist it with a needle under the linen tester. Count plies.
4. Compare your count, your ply-adjusted count and the label. Record all three.
5. **Design.** On graph paper, draw an 8-wide, 16-tall motif (a heart, a cross, a letter). Each row is one pick; each square is one warp end (filled = up).
6. Punch one card per row: a hole where the square is filled.
7. **Weave.** Warp the loom with 8 ends. For each pick, hold the card above the warp, lift the ends where there are holes (with your fingers or a pick-up stick), pass the weft, and beat. Use a contrasting weft for the motif rows.
8. **Conclude.** Did any labels inflate the count? Did your card program weave the motif you drew?
9. **Repeat round.** Swap two cards on purpose and weave again. What does a single programming error look like in cloth?

Tips

- On a plain weave, rows that lift alternate ends give the ground; your motif rows lift more ends together, making floats that show the pattern.
- Long floats snag; keep motif floats to five ends or fewer.
- Label each card with its row number in pencil. Lyon card punchers numbered every card.

Check your work

- ☐ I counted threads accurately in at least four fabrics and checked plies.
- ☐ I compared label and true counts and explained any difference.
- ☐ I programmed and wove a card-driven motif and tested the effect of an error.

LAB NOTEBOOK

1. Draw the Jacquard mechanism simply: cards, needles, hooks, cords, warp ends. Show what a hole does.
2. Tape in your motif chart, a few punched cards and the woven result.
3. Write a one-paragraph buying guide for sheets that a friend could follow in a store.

KEY FORMULAS

$$\begin{aligned}\text{thread count} &= \text{EPI} + \text{PPI} \\ \text{patterns per card} &= 2^n \quad (n = \text{number of hooks}) \\ \text{patterns per card} &= 2n \quad (n = \text{number of hooks})\end{aligned}$$

From history. By around 1812 there were already thousands of Jacquard looms at work in France, and the machine soon crossed to England and America. Its punched-card chains were still being used on industrial looms long after the first electronic computers, and modern looms use electronic Jacquard heads that read pattern files instead of cards.

WORKED EXAMPLES

Example 1. Under the linen tester, a sheet shows 52 ends and 48 picks in $\frac{1}{2}$ inch. Each yarn untwists into 2 plies, and the label says “400 thread count.” Find the true count and the ply-inflated count.

Show solution

1. EPI and PPI: $52 \times 2 = 104$, $48 \times 2 = 96$.
2. True count: $104 + 96 = 200$.
3. Counting each ply: $200 \times 2 = 400$.

Answer: The true count is 200; the label's 400 counts each ply.

Example 2. A small Jacquard has 8 hooks. How many different lift patterns can one card encode? How many cards for a motif 60 picks tall?

Show solution

1. $2^8 = 256$.
2. One card per pick: 60 cards.

Answer: 256 patterns per card; 60 cards for the motif.

Example 3. Jacquard's woven portrait used about 24,000 cards. If the loom wove 2 picks a minute with a skilled weaver, how many hours of weaving is that?

Show solution

1. $24,000 \div 2 = 12,000$ min = 200 h

Answer: About 200 hours of weaving at that assumed pace, not counting the months of card punching.

PRACTICE

1. **Easy** What did a hole in a Jacquard card do?

Show answer

Let a needle pass, so its hook lifted a warp end for that pick.

2. **Easy** Whose job did the Jacquard loom replace?

Show answer

The drawboy, who pulled cords to lift warp ends on a draw loom.

3. **Easy** Define thread count.

Show answer

Ends per inch plus picks per inch.

4. **Medium** A fabric has 88 EPI and 80 PPI. Find its thread count. Is it a percale count?

Show answer

168; no, percale requires at least 180.

5. **Medium** A label says 800; the yarns are 4-ply singles. What is the likely true count?

Show answer

200.

6. **Medium** How many patterns can a card with 12 hooks encode?

Show answer

$$2^{12} = 4,096,212 = 4,096$$

7. **Medium** Name three things besides thread count that decide sheet quality.

Show answer

Fiber (staple length), yarn quality (combed, singles or two-ply, evenness), weave (percale or sateen) and finish.

8. **Hard** You count 36 ends and 34 picks in $\frac{3}{8}$ in. Find the thread count.

Show answer

EPI 96, PPI ≈ 90.7 ; count about 187.

9. **Hard** A seller doubles the count by using 2-ply yarns and counting plies, and charges 40% more. Explain why a careful buyer should not pay it.

Show answer

Two-ply yarns of very fine singles may weigh no more than one good singles; the yarn count in the cloth has not doubled, only the number on the label, and fine plied yarn can make a heavier, less breathable sheet.

10. **Hard** How did Ada Lovelace connect the Jacquard loom to Babbage's engine?

Show answer

She wrote that the Analytical Engine would weave algebraical patterns just as the Jacquard loom weaves flowers and leaves: both are controlled by punched-card instructions.

11. **Challenge** A sheet is 100 EPI $\times$ 100 PPI of 15-tex singles; another is 150 $\times$ 150 of 2-ply yarn made of two 5-tex singles (10 tex total). Which has more cotton per square inch? Calculate.

Show answer

Sheet 1: $200 \times 15 = 3,000$ 200 $\times 15 = 3,000$ tex-inches per square inch. Sheet 2: $300 \times 10 = 3,000$ 300 $\times 10 = 3,000$. The same cotton; sheet 2 would be labeled 600 by counting plies, yet it holds no more fiber.

COMMON MISTAKES

- Equating a big thread count with a better sheet. Fiber, yarn and weave matter as much or more.
- Counting threads on the diagonal or across a seam. Count in the open field, along one yarn.
- Crediting Jacquard with the first punched pattern device. He built on Bouchon's and Vaucanson's ideas and made them work.

Make it a game · Card Code. One player secretly draws a 5 $\times$ 5 picture on graph paper and punches it as five cards (holes for filled squares). The other player gets only the cards and must redraw the picture. Then switch. A perfect copy scores five points; one point off for each wrong square. Bonus: decode a card held up for three seconds only.

5.4 WILLIAM LEE'S FRAME AND THE KNIT LOOP

OBJECTIVES

- Tell the story of William Lee's stocking frame (1589) and the rise of machine knitting.
- Distinguish weft and warp knits, courses and wales, and jersey, rib, purl and interlock structures, and explain why knits stretch, curl and run.
- Knit and analyze jersey and rib swatches and calculate stitch density and stretch.

Warm-up. Look at a T-shirt and a sock under your magnifier. Find the rows of loops running across (courses) and the columns running up and down (wales). Stretch each crosswise and lengthwise: which way stretches more?

WATCH

As Poor as a Stockinger - An Introduction to the Framework Knitters' Museum

Framework Knitters' Museum · 7:37

<https://www.youtube.com/watch?v=QaZw0pCLsRc>

WHEN TO WATCH

After “The story.” Watch the frame's row of needles and sinkers make a whole row of loops at once.

Note: The Framework Knitters Museum at Ruddington, near Nottingham; a small museum channel.

BACKUP VIDEO

Using a Circular Knitting Machine

The Henry Ford · 1:21

https://www.youtube.com/watch?v=ccepDc_4gV4

A historic circular knitting machine at work in The Henry Ford's Greenfield Village; watch the needles form a tube of knit fabric.

KEY TERMS

weft knit

A knit in which one yarn travels across, forming a row of loops (a course) that interlocks with the row below; hand knitting and most T-shirt fabric.

course and wale

A course is a crosswise row of loops; a wale is a lengthwise column of loops.

rib knit

A weft knit alternating columns of knit and purl stitches, very stretchy crosswise and quick to spring back; used for cuffs and collars.

warp knit

A knit in which many yarns run lengthwise, each looping into its neighbors in zigzags; tricot and raschel are warp knits. They resist running.

jersey (single knit)

A weft knit with knit stitches on the face and purl bumps on the back; it curls at the edges and can run.

interlock

A double knit made of two interlocked rib layers, smooth on both sides, stable and non-curling.

CORE IDEAS

The story. In 1589 William Lee, a clergyman of Calverton near Nottingham, England, built a machine to knit stockings, the first knitting machine. A long-told story says he was moved to it watching his wife or sweetheart knit by hand; that may be legend. What is record is that he sought a patent from Queen Elizabeth I and was refused, the queen reportedly worried for the hand knitters, and that he took his frame to France, where he died. His brother James brought the frame back to England, and the framework knitting trade grew up around Nottingham and Leicester. Lee's design, with improvements, made stockings for more than two centuries.

How they figured it out. A hand knitter makes one loop at a time. Lee's frame had a row of fine bearded needles, one for each wale, with a springy hook (the beard) that could be pressed closed. Sinkers pushed the yarn into loops between all the needles at once; a

presser bar closed the beads so the old loops slid over and off, forming a whole course in one motion. The frame knitter worked it with hands and feet. Later inventors added the latch needle (1847), circular machines that knit tubes continuously, and power drive, and today circular knitting machines with thousands of needles turn out T-shirt fabric by the mile.

The fabric science. A knit is made of loops pulled through loops. Each loop can bend, open and slide, so knits stretch, especially crosswise, and spring back; that is why they are comfortable and why T-shirts need no buttons. Jersey's knit side is smooth V's, its purl side bumpy; the unequal sides make its edges curl. Rib alternates knit and purl columns, which draw together, so it hugs and recovers. Interlock knits two ribs together so tightly that it is smooth on both sides and does not curl. Because a weft knit's course is one long yarn, a cut or broken loop can run, or ladder, down the wale. Warp knits are built of many lengthwise yarns looping into their neighbors, so they resist runs, which is why tricot is used for linings and many stable knits.

Measuring knits. Knitters and knit engineers count courses per inch (CPI) and wales per inch (WPI); their product is the stitch density in loops per square inch. Hand knitters call the same thing gauge, given as stitches and rows per 4 inches, and use it to calculate how many stitches to cast on for a given width.

The studio lab. You will knit a swatch of jersey (stockinette) and one of 1×1 rib on the same needles with the same yarn, then measure their widths, stitch density and crosswise stretch. A small cut in a jersey swatch will show you how a run starts.

PICTURE STUDY



The Knitting Lesson, Jean-François Millet, 1869 · Oil on canvas · Saint Louis Art Museum

Image: [Wikimedia Commons](#), public domain

Millet painted this scene of a mother teaching her daughter to knit near the end of his life. In French farm households, girls learned to knit young, and stockings for the whole family came from their needles. Millet makes the teaching itself the subject: hands guiding hands.

Look closely

- Find the needles. How many are there, and is the child knitting flat or in the round?
- Look at the mother's hands. Is she knitting herself, or guiding the girl's hands?
- Look at the girl's face. What is she concentrating on?
- Find the yarn. Where is the ball, and how is the yarn tensioned?

Talk about it

1. A hand knitter forms one loop at a time; Lee's frame formed a whole row. How long might this girl take to knit one stocking?
2. Why would knitting be taught by a parent rather than learned from a book in 1869?
3. What does Millet seem to believe about this kind of work and this kind of teaching?

Safety first. Knitting needles are pointed: store them in a case or a jar, never loose in a seat, and keep them away from toddlers. Use small scissors for the run test, cutting away from your fingers. Count pins and needles at the end of the session.

Jersey and Rib: Knit, Measure, Ladder

Question: How do jersey (stockinette) and 1×1 rib differ in width, stitch density and stretch when knitted from the same yarn on the same needles? You will knit both swatches and measure them, then start a ladder on purpose.

You will need

- US 8 (5 mm) knitting needles and about 60 yd of smooth, light-colored worsted-weight wool or cotton yarn
- A ruler, the linen tester, small scissors and a crochet hook
- A store-bought T-shirt scrap and a ribbed cuff for comparison

TWO MATCHED SWATCHES

Finished size: Two swatches of 24 stitches × 30 rows, about 5 × 5 in · About 90 minutes

Fabric and notions

- About 60 yd of worsted-weight (class 4) wool or cotton yarn
- US 8 (5 mm) straight needles

How to make it

1. Cast on 24 stitches with a long-tail cast-on.
2. Jersey swatch: knit every right-side row and purl every wrong-side row for 30 rows. Bind off loosely.
3. Cast on 24 stitches again for the rib swatch.
4. Rib swatch: *knit 1, purl 1*, repeat across; on every row, knit the knits and purl the purls as they face you. Work 30 rows. Bind off in pattern.
5. Weave in the ends, then lay both swatches flat without stretching for an hour before measuring.

Fabric check: Smooth, light-colored yarn shows stitches best; avoid fuzzy, dark or novelty yarns for a first analysis. Cotton shows structure clearly but does not spring back like wool, so expect less recovery in the rib. Wool-sensitive students can use cotton or acrylic and note the fiber in their results.

Steps

1. **Hypothesis.** Predict which swatch will be narrower relaxed, which will stretch more, and by roughly how much.
2. Knit both swatches following the pattern card.
3. Measure each swatch's relaxed width and height. Count stitches and rows in 2 in and calculate gauge, CPI and WPI and stitch density.
4. Stretch each crosswise gently until it resists, measure, and calculate percent stretch. Release and measure again after one minute.
5. Measure CPI and WPI on the store-bought T-shirt and cuff under the linen tester, and compare with your hand knits.
6. **Ladder test.** On the jersey swatch, snip one loop in the middle and pull gently lengthwise. Watch the run travel. Then catch it back up loop by loop with the crochet hook.
7. **Conclude.** Which structure stretched and recovered more? How did hand and machine knits compare in density?
8. **Repeat round.** Knit 10 more rows of jersey on US 6 (4 mm) needles. How do gauge and density change?

Tips

- Lay swatches flat and do not stretch them while measuring; knits change shape easily.
- Count stitches (V's) across, and rows (V's) up one column.
- Fixing a run with a crochet hook is the same skill you need to rescue a dropped stitch.

Check your work

- ☐ I knitted two swatches of equal stitch count and measured both carefully.
- ☐ I calculated gauge, stitch density and percent stretch.
- ☐ I made and repaired a ladder and explained why it ran.

LAB NOTEBOOK

1. Draw the loop structure of jersey (face and back) and of 1×1 rib from above, showing knit and purl columns.
2. Draw a weft knit and a warp knit side by side, with arrows showing which way their yarns travel.
3. Tape in a corner of each swatch beside its gauge and stretch numbers.

KEY FORMULAS

$$\text{stitch density} = \text{CPI} \times \text{WPI}$$

$$\text{stitch density} = \text{CPI} \times \text{WPI}$$

$$\text{stitches to cast on} = \text{gauge (stitches per inch)} \times \text{desired width (in)}$$

$$\text{stitches to cast on} = \text{gauge (stitches per inch)} \times \text{desired width (in)}$$

From history. Framework knitters around Nottingham and Leicester worked their heavy frames at home for generations, often in hardship as prices fell. Their trade gave English the phrase “as poor as a stockinger,” and the Framework Knitters' Museum at Ruddington, near Nottingham, still keeps working frames and the cottages where knitters lived.

WORKED EXAMPLES

Example 1. A T-shirt jersey has 38 courses and 30 wales per inch. Find its stitch density and the loops in one square foot.

Show solution

1. $38 \times 30 = 1,140 \text{ loops/in}^2$ $38 \times 30 = 1,140 \text{ loops/in}^2$.
2. $1,140 \times 144 = 164,160 \text{ loops/ft}^2$ $1,140 \times 144 = 164,160 \text{ loops/ft}^2$.

Answer: 1,140 loops per square inch, about 164,000 per square foot.

Example 2. Your stockinette swatch measures 18 stitches and 24 rows in 4 in. How many stitches do you cast on for a 9-in-wide cowl panel, and how many rows for 12 in?

Show solution

1. Gauge: $18 \div 4 = 4.5 \text{ st/in}$ $18 \div 4 = 4.5 \text{ st/in}$; $24 \div 4 = 6 \text{ rows/in}$ $24 \div 4 = 6 \text{ rows/in}$.
2. Stitches: $4.5 \times 9 = 40.5 \approx 40$ or 41 $4.5 \times 9 = 40.5 \approx 40$ or 41 .
3. Rows: $6 \times 12 = 72$ $6 \times 12 = 72$.

Answer: Cast on about 40 stitches (41 if the pattern needs an odd number) and knit 72 rows.

Example 3. A 4-in-wide rib swatch stretches to 7.2 in under a light pull, and a jersey swatch of the same stitch count measures 5.0 in relaxed and stretches to 6.5 in. Find each crosswise stretch.

Show solution

1. Rib: $\frac{7.2 - 4.0}{4.0} \times 100\% = 80\%$ $\frac{7.2 - 4.0}{4.0} \times 100\% = 80\%$.
2. Jersey: $\frac{6.5 - 5.0}{5.0} \times 100\% = 30\%$ $\frac{6.5 - 5.0}{5.0} \times 100\% = 30\%$.

Answer: Rib stretches 80%, jersey 30%; rib also draws in narrower when relaxed, which is why it is used for cuffs.

PRACTICE

1. Easy Who invented the first knitting machine, and when?

Show answer

William Lee, 1589.

2. Easy Define course and wale.

Show answer

Course: a crosswise row of loops. Wale: a lengthwise column of loops.

3. Easy Why do jersey edges curl?

Show answer

The knit and purl faces are unequal, so the fabric rolls toward one side at the edges.

4. Medium A knit has 24 CPI and 20 WPI. Find its stitch density.

Show answer

480 loops per square inch.

5. Medium Gauge is 5 stitches per inch. How many stitches for a 22-in hat circumference?

Show answer

110.

6. Medium Why do warp knits resist running?

Show answer

Each lengthwise yarn loops into its neighbors in a zigzag, so a broken loop is held by loops from other yarns rather than unraveling along a course.

7. Medium What made Lee's frame faster than hand knitting?

Show answer

It formed a whole course of loops at once with a row of bearded needles, sinkers and a presser bar.

8. Hard Gauge is 22 stitches and 30 rows per 4 in. A scarf must be 7 in wide and 60 in long. Find cast-on stitches and total rows.

Show answer

$5.5 \times 7 = 38.5 \approx 39.5 \times 7 = 38.5 \approx 39$ stitches; $7.5 \times 60 = 450$ rows.

9. Hard A 4-in rib relaxed to 3.2 in when it came off the needle. By what percent did it draw in, and why?

Show answer

$0.8/4.0 = 20\%$; the knit and purl columns pull together, the purls receding behind the knits.

10. Hard Why is interlock often chosen for baby clothes and polo shirts?

Show answer

It is smooth on both sides, stable, does not curl and resists running, yet stays soft and stretchy.

11. Challenge Queen Elizabeth reportedly refused Lee a patent out of concern for hand knitters. Compare her reasoning with the mill story of Unit 4, and give your own judgment.

Show answer

A good answer notes the real hardship to hand knitters and the real benefits of cheaper stockings, compares with the spinning machines' gains and costs, and offers a reasoned judgment (for example, that new tools are good but leaders should help displaced workers adapt).

COMMON MISTAKES

- Measuring a swatch stretched on the needle. Bind off and let it relax first.
- Thinking knits are only for sweaters. Most T-shirts, socks, underlayers and athletic shirts are machine knits.
- Cutting a weft knit without finishing the edge. Stitch or serge cut knit edges, or they may run.

Make it a game · Knit or Woven Lightning Round. A parent pulls ten items from closets: socks, jeans, a T-shirt, a dress shirt, a sweatshirt, a tablecloth, tights, a towel, a polo, a pillowcase. Players have five seconds per item to call “knit” or “woven,” and three more for “weft” or “warp” on knits. One point per correct call; a perfect round earns five bonus points.

5.5 FELT, NONWOVENS AND LACE

OBJECTIVES

- Describe how felt and nonwovens (needle-punched, spunbond, spunlace, fused interfacing) are made and used.
- Distinguish needle lace, bobbin lace and machine lace, and tell the history from Flemish lacemakers to Heathcoat's bobbinet machine.
- Work a first bobbin-lace braid and test the direction-dependence of nonwovens, calculating basis weight and strength ratios.

Warm-up. Find three things in the house that are neither woven nor knitted: a dryer sheet, a felt pad, a reusable grocery bag, a disposable mask, interfacing in a shirt collar, a coffee filter. Tear each a little (with permission) and look at the edge under your magnifier. What holds the fibers together?

WATCH

bobbin lace basics beginner series, video 1

[Galicia Bee Designs](#) · 2:33

https://www.youtube.com/watch?v=5L7_C-q_47Y

WHEN TO WATCH

After “The story.” Watch the lacemaker's hands: count the bobbins she moves for one stitch.

BACKUP VIDEO

Lace in The Met Collection | Insider Insights

[The Met](#) · 16:52

<https://www.youtube.com/watch?v=G57O2utaX88>

A museum curator shows lace from the collection up close; look for the differences between needle and bobbin lace.

KEY TERMS

nonwoven

A fabric made directly from fibers or filaments bonded by friction, heat, adhesive or entanglement, without spinning yarn.

spunbond

A nonwoven of continuous filaments laid as a web and bonded with heat, used for reusable bags, crop covers and medical gowns.

bobbin lace

Lace made by crossing and twisting many threads wound on bobbins, held in place with pins on a pillow.

needle-punched and spunlace

Needle-punched nonwovens are tangled by barbed needles; spunlace (hydroentangled) nonwovens by fine water jets.

needle lace

Lace built stitch by stitch with a needle and thread, usually buttonhole stitches over a framework of threads.

basis weight

The mass per area of a nonwoven, in g/m², the same measure as fabric weight.

CORE IDEAS

The story. Lace rose to splendor in the 1500s and 1600s. Venetian needle-lace makers built raised, sculptural lace stitch by stitch; Flemish lacemakers in Bruges, Brussels and Mechelen made bobbin lace of fine linen thread. Lace collars and cuffs were so costly that laws limited who could wear them. In Delft, around 1669–70, Johannes Vermeer painted a young woman bent over her lace pillow, bobbins in her fingers, the threads so fine they nearly vanish. Then machines arrived: in 1808–1809 John Heathcoat of England patented the bobbinet machine, which made the net ground of lace by machine, and John Levers's machine of 1813 soon made patterned lace too.

How they figured it out. Bobbin lace is pure geometry. Threads are wound on bobbins in pairs and hung from pins on a firm pillow, following a pricked pattern (a pricking). Every stitch is made of just two moves: a *cross* (the middle two bobbins of four cross left over right) and a *twist* (each pair twists right over left). Cross–twist–cross is a cloth stitch; cross–twist is a half stitch. Pins hold each stitch

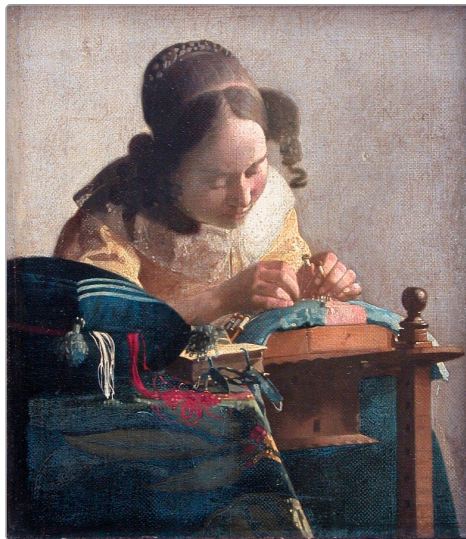
in place until the next ones lock it. Machine lace copied these moves with thousands of threads at once. Nonwovens skip yarn altogether: felt by matting wool (Unit 2), and since the 1900s by machines that lay webs of fibers or filaments and lock them with barbed needles, water jets, heat or adhesive.

The fabric science. Nonwovens are made for jobs. They do not fray, cost little, and can be engineered to filter, absorb, insulate or stiffen. Fusible interfacing, glued to the inside of collars and facings, is a light nonwoven. Many nonwovens are stronger in the direction the web was laid (the machine direction) than across it, because more fibers line up that way; testing strips cut both ways shows it. Their weakness is drape and recovery: most nonwovens hang stiffly and cannot stretch back like a knit. Lace's open structure, meanwhile, makes it light and decorative but delicate: every hole is a place where only a few threads carry the load.

Look closely. Under 10×, a woven fabric shows yarns crossing at right angles, a knit shows loops, felt shows a random mat of fibers, a spunbond shows bonded points like a quilted dot pattern, and lace shows twisted and crossed threads around open holes.

The studio lab. You will set up a simple lace pillow with clothespin bobbins and work a short braid in cloth stitch and half stitch. Then you will cut strips of a nonwoven interfacing or spunbond bag in two directions and compare their strength.

PICTURE STUDY



The Lacemaker, Johannes Vermeer, c. 1669–70 · Oil on canvas · Musée du Louvre, Paris

Image: [Wikimedia Commons](#), public domain

This is one of the smallest paintings Vermeer ever made, only about 9 by 8 inches. A young woman leans over her lace pillow, holding bobbins and placing a pin. Vermeer painted the threads spilling from a sewing cushion in the front as soft, almost liquid strokes, while the thread she works is a single fine line of light.

Look closely

- Find the bobbins in her hands. How many threads is she working at once?
- Find the pin she is placing. What will it hold?
- Look at the red and white threads spilling from the cushion in front. How is Vermeer's painting of them different from the sharp lines elsewhere?
- Find the small book on the table. Some think it is a prayer book. Why might it be there?

Talk about it

1. Lacemaking demanded steady hands, sharp eyes and long hours. What in her posture shows that?
2. The finished lace might become a collar worth more than a workman's yearly wage. Why was it so costly?
3. Vermeer could have painted the finished lace on a wealthy lady. Why do you think he painted the maker instead?

Safety first. Keep dressmaker pins in the pincushion and count them before and after: a lace pillow uses many pins. Clothespin bobbins should be smooth; sand any splinters. Cut nonwoven strips with shears or a rotary cutter on a mat, blade closed when set down.

A First Lace Braid and the Nonwoven Strip Test

Question: Can you make a regular bobbin-lace braid using only crosses and twists, and is a nonwoven stronger in one direction than the other? Two short investigations, one craft and one test.

You will need

- A firm foam board or a stack of corrugated cardboard (a lace pillow), dressmaker pins and graph paper
- 8 clothespins or lace bobbins and about 8 yd of smooth size 10 cotton crochet thread or perle cotton
- A spunbond bag or a sheet of nonwoven interfacing, a ruler, shears and the bucket rig

CLOTH-STITCH AND HALF-STITCH LACE BRAID

Finished size: A braid about $\frac{3}{4}$ in wide and 4–6 in long · About 60 minutes

Fabric and notions

- 4 pairs of bobbins (8 clothespins), each pair wound with about 1 yd of size 10 cotton crochet thread, the two bobbins of a pair joined by the middle of the thread
- A strip of graph paper with pinholes marked every $\frac{1}{4}$ in down two parallel lines $\frac{3}{4}$ in apart (the pricking)
- About 20 dressmaker pins

How to make it

1. Wind thread onto each clothespin, leaving about 12 in between the two bobbins of a pair. Hang the four pairs side by side over two pins at the top of the pricking.
2. Learn the moves with the middle four bobbins: **cross** (bobbin 2 over bobbin 3) and **twist** (bobbin 2 over 1 and bobbin 4 over 3).
3. Cloth stitch: cross, twist, cross. Work the leftmost pair (the weavers) across through each pair in cloth stitch.
4. At the edge, twist the weavers twice, set a pin in the next hole inside them, and work back across.
5. Continue for 2 in, setting a pin at each edge hole. Then switch to half stitch (cross, twist) for 2 in and see how the texture opens up.
6. Finish by tying the pairs off in overhand knots and removing the pins only after the braid is pressed flat.

Fabric check: Smooth, firm cotton thread (size 10 crochet cotton or perle 8) is easiest to see and handle; avoid fuzzy or stretchy yarn. Linen lace thread is traditional but slippery for a first try.

Steps

1. **Hypothesis.** Predict which lace stitch will be denser, and whether the nonwoven will be stronger along or across its length.
2. Make the lace braid following the pattern card. Count the stitches per inch in each section.
3. Photograph the braid under the magnifier and compare cloth stitch and half stitch.
4. **Nonwoven test.** Find the machine direction of the nonwoven (look for fiber alignment, or the long direction of the roll or bag panel).
5. Cut five 1 × 6 in strips along the machine direction and five across it. Break each with the bucket rig and record the loads.
6. Weigh a 10 × 10 cm square and calculate basis weight; calculate the MD/CD ratio.
7. **Conclude.** Which lace stitch was firmer? Was the nonwoven direction-dependent, and by how much?
8. **Repeat round.** Work 1 in of the braid with an extra twist on every pair between stitches. How does the lace change?

Tips

- Say the moves aloud: “cross, twist, cross.” Lacemakers have always worked to a rhythm.
- Keep the weaver pair snug at each pin, but do not pull so hard that the edge draws in.
- Many lacemakers learned exactly this braid first, centuries ago and today.

Check your work

- ☐ I worked a lace braid in cloth stitch and half stitch with even edges.

- ☐ I tested nonwoven strips in two directions and calculated basis weight and MD/CD ratio.
- ☐ I explained both results with the structure I saw under the magnifier.

LAB NOTEBOOK

1. Draw the four-bobbin moves: cross and twist, with numbered bobbins before and after.
2. Draw what you see under 10× for a woven, a knit, a felt, a spunbond and a lace.
3. Tape in your lace braid and a nonwoven test strip with their results.

KEY FORMULAS

$$\text{basis weight (g/m}^2\text{)} = \frac{\text{mass (g)}}{\text{area (m}^2\text{)}}$$

$$\text{basis weight (g/m}^2\text{)} = \text{area (m}^2\text{)} \times \text{mass (g)}$$

$$\text{MD/CD ratio} = \frac{\text{strength in machine direction}}{\text{strength in cross direction}}$$

$$\text{MD/CD ratio} = \frac{\text{strength in cross direction}}{\text{strength in machine direction}}$$

From history. In the 1600s, lacemaking supported thousands of families in Flanders, France and the English Midlands, and lacemakers sang counting rhymes to keep the pattern. When machines took over the plain nets and edgings, hand lacemakers turned to finer and more original designs, and lace schools kept the craft alive into the twentieth century.

WORKED EXAMPLES

Example 1. A 10 × 10 cm square of fusible interfacing weighs 0.42 g. Find its basis weight in g/m² and oz/yd².

Show solution

$$1. \frac{0.42 \text{ g}}{0.01 \text{ m}^2} = 42 \text{ g/m}^2$$

$$2. 42/33.9 = 1.2 \text{ oz/yd}^2$$

Answer: 42 g/m², about 1.2 oz/yd², a lightweight interfacing.

Example 2. Strips of a spunbond bag fabric broke at 3.6 kg in the machine direction and 2.4 kg in the cross direction. Find the MD/CD ratio.

Show solution

$$1. \frac{3.6 \text{ kg}}{2.4 \text{ kg}} = 1.5$$

Answer: 1.5: the fabric is half again as strong along the machine direction. Cut bag handles that way.

Example 3. A bobbin-lace edging uses 6 pairs of bobbins. Each pair's thread is consumed at about 1.6 times the lace length. How much thread must be wound for 36 in of edging, with 12 in extra per bobbin for starting and finishing?

Show solution

$$1. \text{ Bobbins: } 6 \times 2 = 12$$

$$2. \text{ Per bobbin: } 36 \times 1.6 + 12 = 69.6 \text{ in}$$

$$3. \text{ Total: } 12 \times 69.6 = 835 \text{ in} \approx 23 \text{ yd}$$

Answer: About 70 in per bobbin, 23 yd in all, on these assumptions.

PRACTICE

1. **Easy** Name three ways nonwoven fibers can be bonded.

Show answer

Any three: needle-punching, water jets (spunlace), heat (thermal bonding/spunbond), adhesive, felting.

2. **Easy** What are the two moves of every bobbin-lace stitch?

Show answer

Cross and twist.

3. **Easy** Who painted The Lacemaker, and about when?

Show answer

Johannes Vermeer, about 1669–70.

4. **Medium** A 20×20 cm nonwoven weighs 3.2 g. Find its basis weight.

Show answer

$$3.2/0.04 = 80 \text{ g/m}^2 \quad 3.2/0.04 = 80 \text{ g/m}^2$$

5. **Medium** MD strength 5.0 kg, CD 2.0 kg. Find the ratio and say which way to cut a strap.

Show answer

2.5; cut along the machine direction.

6. **Medium** Why do nonwovens not fray?

Show answer

There are no yarns to pull out; fibers are bonded or entangled throughout.

7. **Medium** What did John Heathcoat's 1808–1809 machine make?

Show answer

Bobbinet: machine-made net, the ground of lace.

8. **Hard** Give one reason a nonwoven interfacing suits a shirt collar and one reason it would make a poor shirt body.

Show answer

Suits: light, stiff, stable, does not fray, fuses in place. Poor body: no drape or stretch-recovery, weak in abrasion and laundering.

9. **Hard** A lace edging needs 8 pairs with consumption $1.8 \times$ lace length plus 10 in per bobbin. Find total thread for 24 in of lace.

Show answer

$$\text{Per bobbin } 24 \times 1.8 + 10 = 53.2 \text{ in} \quad 24 \times 1.8 + 10 = 53.2 \text{ in}; 16 \text{ bobbins: } 851 \text{ in} \approx 23.6 \text{ yd} \quad 851 \text{ in} \approx 23.6 \text{ yd.}$$

10. **Hard** Describe how to tell needle lace from bobbin lace under a magnifier.

Show answer

Needle lace shows looped buttonhole stitches built up over threads, often with raised edges; bobbin lace shows threads that cross and twist in woven-looking cloth and half stitches and plaited bars.

11. **Challenge** Machine lace made lace affordable but ended many hand lacemakers' livelihoods. How is this like the stories of Lee's frame and the spinning mills, and what continues to give hand lace value today?

Show answer

Same pattern: machines cut cost and widened use but displaced hand workers. Hand lace keeps value as an art: unique design, finer control, heritage skills, and the meaning of a gift made by hand.

COMMON MISTAKES

- Removing lace pins too soon. The stitches open; leave pins in until a good length is done.
- Cutting nonwoven pattern pieces without checking direction. Strength and stretch can differ by direction.
- Calling all net-like fabrics lace. Lace has a designed structure of crosses, twists or needle loops; tulle is machine net.

Make it a game · Under the Glass. A parent prepares eight tiny snippets (woven, jersey knit, rib knit, felt, spunbond, interfacing, lace, tulle) taped to an index card and numbered. Players get two minutes with the linen tester to name each structure. One point each; two for correctly naming needle versus bobbin lace if a sample is included.

UNIT 5 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (7 pts)
Name the loom's three basic motions and the parts that perform each.
2. (7 pts)
Explain why the lengthwise grain is the most stable and what the bias is.
3. (7 pts)
A 16-in-wide runner, 54 in finished, at 10 EPI with 10% take-up and 24 in loom waste. Find ends, warp length and total warp yardage.
4. (7 pts)
Compare plain, twill and satin weaves: structure and one typical fabric each.
5. (7 pts)
A 10×10 cm square weighs 2.75 g. Find GSM and oz/yd², and classify the weight.
6. (7 pts)
Why is denim's face darker than its back?
7. (7 pts)
Explain how a Jacquard card controlled the loom and how the idea reached computing.
8. (7 pts)
A sheet shows 47 ends and 43 picks per $\frac{1}{2}$ in, made of 3-ply yarns, and is labeled 540. Find the true count and explain the label.
9. (6 pts)
How many patterns can a card with 10 hooks encode?
10. (6 pts)
Tell the story of William Lee's frame in three sentences, marking any legend.
11. (7 pts)
Distinguish weft knits from warp knits, and jersey from rib, with a use for each.
12. (6 pts)
Gauge is 20 stitches and 28 rows per 4 in. Find stitches for a 10-in panel and rows for 15 in.
13. (6 pts)
A spunbond strip breaks at 4.2 kg MD and 2.8 kg CD; a 10×10 cm square weighs 0.85 g. Find the ratio and basis weight.
14. (6 pts)
Describe the two moves of bobbin lace and the stitches they make.
15. (7 pts)
Short essay (5–7 sentences): A shopper asks you how to choose good sheets. Using this unit, explain what thread count tells and does not tell, and what else to check.

UNIT PROJECT: A FABRIC-ANALYSIS NOTEBOOK

Build a reference notebook of at least twelve fabrics: at least six woven (plain, twill and satin each represented), three knit (jersey, rib and one other) and three nonwoven or lace. Each page has a swatch, a magnifier sketch of its structure, and a spec line: fiber, construction, counts (EPI $\times$ PPI or CPI $\times$ WPI), weight in g/m² and oz/yd², and best uses.

Add your Lesson 5.1 woven sampler, your Jacquard motif, your knit swatches and your lace braid as the “made by me” section, and finish with a one-page buyer's guide to choosing fabric by structure and weight for three real projects.

LOOK FOR	WHAT IT MEANS
Accuracy	Constructions, counts and weights are measured and identified correctly.
Range	The notebook covers woven, knit, nonwoven and lace structures as required.
Craft	The handmade samplers show even work and honest improvement from first to last.
Clarity	Sketches, spec lines and the buyer's guide could be used by someone else in a fabric store.
Records	Measurement method and any re-measurements are noted.

ANSWER KEY

1. Shedding (harnesses and heddles lifted by treadles), picking (shuttle carries weft through the shed), beating (beater and reed press the pick).
2. Warp is held taut on the loom, usually stronger and more twisted, so it stretches least. The bias is the 45° diagonal, which stretches most.
3. $160 \text{ ends}; 54 \times 1.1 + 24 = 83.4 \text{ in}$
 $54 \times 1.1 + 24 = 83.4 \text{ in}; 160 \times 83.4 = 13,344 \text{ in} \approx 371 \text{ yd}$
 $160 \times 83.4 = 13,344 \text{ in} \approx 371 \text{ yd}$.
4. Plain: over one, under one (muslin, percale). Twill: floats stepping by one, diagonal lines (denim, gabardine). Satin: long floats with separated interlacings, smooth and lustrous (satin, sateen).
5. 275 g/m^2 ; 8.1 oz/yd^2 ; a bottom weight.
6. It is a warp-faced twill: indigo-dyed warp floats on the face; undyed weft shows on the back.
7. Holes let needles pass so their hooks lifted individual warp ends; blanks left them down, one card per pick. Babbage planned punched-card input for his Analytical Engine, Lovelace compared it to the Jacquard loom, and Hollerith's cards tabulated the 1890 census, leading to punched-card computing.
8. $\text{EPI } 94 + \text{PPI } 86 = 180 \text{ true count}$; counting each of 3 plies gives 540.
9. 1,024.
10. In 1589 the clergyman William Lee built a stocking frame, the first knitting machine (the sweetheart story is a legend). Queen Elizabeth refused him a patent, and he took the frame to France. His brother brought it back, founding framework knitting around Nottingham.
11. Weft knit: one yarn forms courses across (T-shirts, hand knits); warp knit: many lengthwise yarns loop into neighbors, run-resistant (tricot linings). Jersey: knit face, purl back, curls (T-shirts); rib: alternating knit and purl columns, very stretchy (cuffs).
12. 50 stitches; 105 rows.
13. 1.5; 85 g/m^2 .
14. Cross (middle bobbins cross left over right) and twist (each pair twists right over left). Cross-twist-cross is cloth stitch; cross-twist is half stitch.
15. A strong answer defines thread count, explains ply inflation and the 2005 FTC advice, recommends a true count around 200–400, and adds fiber (long-staple cotton, linen), yarn quality, weave (percale vs. sateen), weight and finish, with honest trade-offs.

FINISHES, COLOR AND CARE

Cloth fresh from the loom is rarely finished. It is gray, stiff, and may shrink, wrinkle, burn or stain. This unit follows it through the dye house, the print works and the finishing room: natural dyes fixed with mordants, from madder red to the costly purple Lydia sold; William Perkin's accidental mauve of 1856 and the chemists' dyes that followed, each matched to its fiber; printing by block, roller and screen; and the finishes that preshrink, smooth, shed water and resist flame.

Then the unit turns to the closet. You will learn what the law requires on a garment's fiber and care labels and why, read every care symbol, and use real chemistry (surfactants, enzymes and oxidizers) to remove stains in a controlled lab. The Triangle Shirtwaist fire of 1911 is told briefly as fire-safety history, because the laws that came from it still protect workers today. Labs include a dye-selectivity test, a natural dye bath, a printed repeat, a finish test and a stain and colorfastness lab, all done with a parent present and with dye pots kept apart from food.

PREREQUISITES

- Units 1–3: cellulose, protein and synthetic fibers and their chemistry
- A parent present for every dye bath, and a pot, jars and spoons set aside for craft use only
- Rubber gloves, an apron and a well-ventilated work space

MASTERY CHECKLIST

- ☐ I can explain how mordants fix natural dyes and how a vat dye like indigo works.
- ☐ I can tell the story of Perkin's mauve and match the main dye classes to the fibers they dye.
- ☐ I can describe block, roller and screen printing and plan a printed repeat.
- ☐ I can explain Sanforizing, permanent press, water repellency and flame resistance, and tell the Triangle Shirtwaist fire's lessons for safety.
- ☐ I can read every U.S. care symbol and explain the FTC fiber-content and care-label rules.
- ☐ I can remove common stains with the right chemistry and test colorfastness, calculating weight of fiber, dilution and shrinkage.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **FTC: Clothes Captioning: Complying with the Care Labeling Rule:** Free. The Federal Trade Commission's plain-language guide to what care labels must say; search the FTC's business guidance pages for it.
- **A dye-only pot and two quart canning jars:** A thrift-store stainless pot and jars, marked “craft only,” keep dye work away from food for good.
- **Pickling alum and cream of tartar:** Sold in grocery spice aisles; the mordant for Lesson 6.1. Store them labeled with the craft supplies once opened.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

6.1 Madder, Indigo and Lydia's Purple	3 sessions of 50–90 minutes
6.2 Perkin's Mauve and the Dye Chemist's Toolbox	3 sessions of 50–90 minutes
6.3 Printing Cloth: Blocks, Rollers and Screens	3 sessions of 50–90 minutes
6.4 Finishes: Sanforizing, Permanent Press and Fire Safety	3 sessions of 50–90 minutes
6.5 Care Labels and the Chemistry of Stains	3 sessions of 50–90 minutes

6.1 MADDER, INDIGO AND LYDIA'S PURPLE

OBJECTIVES

- Describe the great natural dyes (madder, indigo, weld, cochineal, Tyrian purple) and where each came from.
- Explain how a mordant binds a dye to a fiber and how indigo dyes by reduction and oxidation.
- Dye wool and cotton with and without a mordant and calculate weight-of-fiber amounts and bath ratios.

Warm-up. Rub a slice of beet, a smear of turmeric and a used tea bag each onto a white cotton scrap. Rinse them under the tap. Which colors stayed? Write down your guess of why some colors cling and some wash away.

WATCH

Iron Age Dyes: Woad, Weld & Madder

[Sally Pointer](#) · 15:12

<https://www.youtube.com/watch?v=ESsnU-ECYnw>

WHEN TO WATCH

After “How they figured it out.” Watch for the plant part used for each dye and for the moment a mordant goes into the pot.

Note: An experimental archaeologist dyes wool with plant dyes and alum; watch for the scouring, the mordant bath and the colors madder and woad give.

BACKUP VIDEO

How Natural Dyes Work | Ask Textile History

[Kristine Vike](#) · 17:30

<https://www.youtube.com/watch?v=tO8aRw-CQRA>

A textile historian explains how natural dyes actually bond to fibers, for review before the lab.

KEY TERMS

mordant

A metal salt, most often alum (potassium aluminum sulfate), applied to fiber so that a dye can bind to it firmly through the metal.

vat dye

An insoluble dye, such as indigo, that is chemically reduced to a soluble form in an alkaline vat, soaked into the fiber, then oxidized back to its insoluble color in air.

weight of fiber (WOF)

Dyers measure dye and mordant as a percent of the dry fiber's weight: 15% WOF alum for 100 g of wool is 15 g.

madder

A plant (*Rubia tinctorum*) whose roots give alizarin, the source of reds from Turkey red to the British soldier's coat.

Tyrian purple

The ancient purple dye from murex sea snails, so costly that purple became the color of kings.

bath ratio

The ratio of the dye bath's water weight to the fiber's weight, such as 30:1.

CORE IDEAS

The story. When Paul came to Philippi, among the first to hear him was “a certain woman named Lydia, a seller of purple, of the city of Thyatira.” Thyatira, in what is now western Turkey, was known for its dyers, and purple cloth was among the most precious goods of the ancient world. True Tyrian purple came from murex sea snails: each snail yields only a drop of colorless secretion that turns purple in sunlight. In 1909 the chemist Paul Friedländer extracted the dye from about 12,000 snails and obtained only about 1.4 grams. Little wonder that purple meant wealth and royalty, and that Lydia, a businesswoman in such a trade, could open her house to Paul and his companions.

How they figured it out. Most plant colors wash out of cloth, as your warm-up showed. Dyers learned long ago that some substances fix them. Boiling the fiber first with alum, a mineral salt, made madder's red cling through washing and sunlight. The aluminum ions

The fabric science. Dye molecules carry a color-producing part (a chromophore) that absorbs some wavelengths of light and reflects others. To stay put, a dye must bond to the fiber or be trapped inside it. Protein fibers (wool, silk) take natural dyes and mordants most readily, because their many chemical groups grab metal ions and dye molecules. Cellulose (cotton, linen) is harder to dye with mordants and often needs tannin first, which is why traditional Turkey-red cotton dyeing took many steps over weeks. Different mordants shift colors too: with madder, alum gives red, iron saddens it toward brown and purple.

The studio lab. You will mordant half of your wool and cotton skeins with alum and then dye all of them in the same onion-skin bath, a natural dye that needs no special supplies. Comparing mordanted and plain skeins, and wool against cotton, will show both of the lesson's ideas in color.

This botanical illustration depicts *Ranunculus repens*. The central figure is the whole plant, showing a thick, horizontal, reddish-brown rhizome with numerous fibrous roots. Several upright stems arise from the rhizome, each bearing a palmately compound leaf with five to seven ovate leaflets. The stems are densely covered with small, yellow, bell-shaped flowers. Surrounding the main plant are four detailed insets: a single flower (top left), a seed (top right), a fruit (bottom left), and a fruit (bottom right).

1. Madder roots were usually grown for three years before harvest. What does that tell you about the cost of red cloth?
2. Why would two batches of madder give slightly different reds?
3. When chemists learned to make alizarin in a factory in 1869, what happened to the madder farmers?

Safety first. Dye with a parent present, in a pot, jars and spoons used only for dyeing, never for food. Wear gloves and an apron, keep the room ventilated, and keep children and pets away from hot dye baths. Weigh alum carefully and store it labeled; wash hands and wipe surfaces when you finish.

STUDIO LAB

Mordant or Not: An Onion-Skin Dye Bath

Question: How much does an alum mordant change the depth and fastness of a natural dye on wool and on cotton? You will mordant half your skeins, dye all of them together, and compare color before and after washing.

You will need

- Four small skeins, about 20 g each: two of wool yarn and two of cotton yarn (undyed, light colored)
- Pickling alum and cream of tartar, a scale, measuring cups
- Dry yellow or red onion skins (about 40 g), a dye-only stainless pot, a mesh bag, tongs, gloves and a thermometer
- A white card and a phone camera for comparing colors

ONION-SKIN GOLD ON WOOL AND COTTON

Finished size: Four dyed skeins of about 20 g each · Two afternoons: mordanting about 1½ hours, dyeing about 2 hours, plus drying

Fabric and notions

- 80 g of undyed yarn: 40 g wool and 40 g cotton, tied into four loose skeins with figure-eight ties
- For the mordanted half (20 g wool + 20 g cotton): 6 g alum (15% WOF) and 2.4 g cream of tartar (6% WOF)
- 40 g of dry onion skins (50% WOF for 80 g of fiber)
- Water for a 30:1 bath ratio in each bath

How to make it

1. Scour all four skeins: soak 30 minutes in hot tap water with a drop of dish soap, then rinse.
2. Mordant one wool and one cotton skein: dissolve the alum and cream of tartar in hot water, add to the dye-only pot with 1.2 L of water, add the wet skeins, heat slowly to about 85 °C (185 °F, steaming, not boiling) and hold 45 minutes. Let cool, then rinse. Tie a small knot in each mordanted skein's tie to mark it.
3. Make the dye: simmer the onion skins in the dye-only pot with 2.4 L of water for 45 minutes. Strain out the skins.
4. Add all four wet skeins to the dye bath together. Heat slowly to about 85 °C and hold 45 minutes, turning gently with tongs. Do not boil or stir hard: the wool can felt.
5. Let the bath cool with the skeins in it. Lift them out, rinse in water of the same temperature until it runs clear, and dry them out of the sun.

Fabric check: Use undyed, light-colored wool (not superwash, which dyes differently) and plain mercerized or unmercerized cotton. Wool must heat and cool slowly and not be agitated, or it will felt. Wool-sensitive students can dye silk or a second pair of cotton skeins instead.

Steps

1. **Hypothesis.** Rank the four skeins from darkest to lightest after dyeing, and predict which will lose the most color in washing.
2. Follow the pattern card, weighing every ingredient and recording temperatures and times.
3. When dry, photograph the four skeins together on a white card in daylight and rate each shade from 1 (palest) to 5 (deepest).
4. **Wash test.** Cut 10 cm from each skein. Wash the four snippets together five times in warm water with dish soap, rinse and dry.
5. Compare washed snippets with the unwashed skeins on the white card and rate the change from 1 (large change) to 5 (no change).
6. **Conclude.** Did the mordant matter more on wool or on cotton? Which skein was most colorfast?
7. **Repeat round.** If you can, dye a snippet of each mordanted skein in a second bath of black tea (tannin) and compare: does tannin deepen the cotton?

8. **Clean up.** Cool and dilute the spent bath and pour it down the drain with running water. Wash the dye-only tools and store them away from the kitchen.

Tips

- Keep wool's temperature changes gradual: never move it from hot water straight to cold.
- Weigh dry fiber before scouring; all WOF amounts are based on dry weight.
- Older dyers' books call for chrome, tin and copper mordants. Do not use them at home.

Check your work

- ☐ I dyed with a parent present in dye-only equipment and recorded every amount.
- ☐ I compared mordanted and unmordanted wool and cotton fairly, before and after washing.
- ☐ I explained my results with the chemistry of mordants and protein versus cellulose.

LAB NOTEBOOK

1. Draw a diagram of a mordant link: fiber – metal ion – dye molecule.
2. Draw the indigo cycle: insoluble blue → reduced yellow-green in the vat → oxidized blue in the air.
3. Tape in snippets of all four skeins, before and after washing, with your ratings.

KEY FORMULAS

$$\text{amount (g)} = \text{fiber mass (g)} \times \frac{\% \text{ WOF}}{100}$$
$$\text{amount (g)} = \text{fiber mass (g)} \times 100\% \text{ WOF}$$
$$\text{water (g, or mL)} = \text{fiber mass (g)} \times \text{bath ratio}$$
$$\text{water (g, or mL)} = \text{fiber mass (g)} \times \text{bath ratio}$$

From history. In 1869 the German chemists Carl Graebe and Carl Liebermann, and independently William Perkin in England, found how to make alizarin, madder's red, from coal tar. Within a few years the great madder fields of France and Holland had almost disappeared, an early example of chemistry reshaping farming.

WORKED EXAMPLES

Example 1. You will mordant 80 g of wool yarn with 15% WOF alum and 6% WOF cream of tartar at a 30:1 bath ratio. How much of each, and how much water?

Show solution

1. Alum: $80 \text{ g} \times 0.15 = 12 \text{ g}$ $80 \text{ g} \times 0.15 = 12 \text{ g}$.
2. Cream of tartar: $80 \text{ g} \times 0.06 = 4.8 \text{ g}$ $80 \text{ g} \times 0.06 = 4.8 \text{ g}$.
3. Water: $80 \times 30 = 2,400 \text{ g} = 2.4 \text{ L}$ $80 \times 30 = 2,400 \text{ g} = 2.4 \text{ L}$.

Answer: 12 g alum, about 5 g cream of tartar, in 2.4 L of water.

Example 2. Onion skins are used at 50% WOF for a medium gold. How many grams for 120 g of fiber, and how many onions if each gives about 4 g of dry skins?

Show solution

1. Skins: $120 \times 0.50 = 60 \text{ g}$ $120 \times 0.50 = 60 \text{ g}$.
2. Onions: $60 \text{ g} \div 4 \text{ g/onion} = 15 \text{ onions}$ $60 \text{ g} \div 4 \text{ g/onion} = 15 \text{ onions}$.

Answer: 60 g of skins, from about 15 onions: save them for a few weeks.

Example 3. Friedländer's 12,000 snails gave about 1.4 g of dye. If dyeing wool deep purple took about 2% WOF, how many snails for one 500 g garment of wool?

Show solution

1. Dye needed: $500 \times 0.02 = 10 \text{ g}$ $500 \times 0.02 = 10 \text{ g}$.
2. Snails per gram: $12,000 \div 1.4 \approx 8,570$ $12,000 \div 1.4 \approx 8,570$.
3. Snails: $10 \times 8,570 \approx 85,700$ $10 \times 8,570 \approx 85,700$.

Answer: On these assumptions, roughly 86,000 snails for one purple garment: why purple was royal.

PRACTICE

1. **Easy** What did Lydia sell, and from what city did she come?

Show answer

Purple (cloth or dye); Thyatira.

2. **Easy** What part of the madder plant gives the dye?

Show answer

The roots.

3. **Easy** What is a mordant, and what is the most common one?

Show answer

A metal salt that binds dye to fiber; alum.

4. **Medium** How much alum at 12% WOF for 250 g of wool?

Show answer

30 g.

5. **Medium** How much water for 150 g of fiber at a 40:1 bath ratio?

Show answer

6,000 g, or 6 L.

6. **Medium** Describe the color change as indigo-dyed cloth leaves the vat, and explain it.

Show answer

Yellow-green turning blue in the air: the soluble reduced indigo is oxidized by oxygen back to insoluble blue indigo inside the fiber.

7. **Medium** Why do natural dyes take more easily on wool than on cotton?

Show answer

Wool's protein has many chemical groups that bind metal mordants and dye molecules; cellulose has fewer such sites and usually needs tannin first.

8. **Hard** A dyer wants 2.5 L of bath at 30:1. How much fiber can she dye?

Show answer

$2,500/30 \approx 83 \text{ g}$ $2,500/30 \approx 83 \text{ g}$

9. **Hard** Cochineal is used at 4% WOF for a strong crimson. A kilogram of dried cochineal holds about 140,000 insects. How many insects for 200 g of wool?

Show answer

Cochineal 8 g $8 \times 140 = 1,120$ $8 \times 140 = 1,120$ insects.

10. **Hard** Why should dye pots and spoons never return to the kitchen?

Show answer

Mordants and dyes, even natural ones, leave residues that should not be eaten, and some mordants are harmful; separate tools prevent any mix-up.

11. **Challenge** Using Acts 16:14–15 and the snail arithmetic, explain what Lydia's trade suggests about her place in Philippi and how the gospel reached her household.

Show answer

Purple was costly and its trade required capital, skill and connections, so Lydia was likely a businesswoman of means with a household and a house large enough to host Paul's company. The Lord opened her heart as she heard Paul, and she and her household were baptized, making her home an early center of the church in Philippi.

COMMON MISTAKES

- Boiling wool in the dye pot. Hold it steaming, not boiling, and do not stir hard.
- Calculating mordant on wet fiber weight. Use dry weight.
- Using a kitchen pot “just this once.” Keep dye equipment separate for good.

Make it a game · Kitchen Color Hunt. Each player gets two minutes to find three foods or plants that stain (beet, turmeric, coffee, berries, spinach). Dab each on a numbered white cotton strip, rinse under the tap and rank which held its color. Players score one point for each color that survives the rinse, and two for predicting the winner before rinsing.

Scripture. “And a certain woman named Lydia, a seller of purple, of the city of Thyatira, which worshipped God, heard us: whose heart the Lord opened, that she attended unto the things which were spoken of Paul.” (Acts 16:14, KJV)

The first convert in Europe named in Acts was a woman in the dye trade. Purple was her business, and the Lord opened her heart in the middle of an ordinary working life.

6.2 PERKIN'S MAUVE AND THE DYE CHEMIST'S TOOLBOX

OBJECTIVES

- Tell the story of William Perkin's discovery of mauveine in 1856 and the synthetic dye industry that followed.
- Match the main dye classes (acid, basic, direct, reactive, disperse, vat) to the fibers they dye and explain why.
- Run a dye-selectivity test on a multifiber strip and calculate depth of shade and dilutions.

Warm-up. Look at the most brightly colored garment you own and read its label. Then imagine the same garment in 1840, before synthetic dyes. Which of its colors could a dyer of 1840 have made with plants and insects, and how bright?

WATCH

Mauve and William Henry Perkin

McGill Office for Science and Society · 4:14

https://www.youtube.com/watch?v=cuAF_3XFYDc

WHEN TO WATCH

After “The story.” Listen for what Perkin was actually trying to make, and what he noticed that others might have thrown away.

BACKUP VIDEO

Chance Discoveries: Synthetic Dye

NBC News Learn · 4:05

<https://www.youtube.com/watch?v=QCcl2u3N6ng>

A second short telling of Perkin's discovery, with the chemistry of coal tar.

KEY TERMS

mauveine

The first synthetic dye sold commercially, discovered by William Perkin in 1856, a purple made from aniline derived from coal tar.

acid dye

A dye that bonds ionically to protein fibers and nylon in an acidic bath.

fiber-reactive dye

A dye that forms a covalent chemical bond with cellulose (cotton, linen, rayon), giving excellent wash fastness.

disperse dye

A small, nearly insoluble dye that dissolves into hydrophobic fibers such as polyester and acetate at high temperature.

depth of shade

The mass of dye as a percent of the fiber's mass; one percent gives a medium shade for many dyes, 4% a deep one.

colorfastness

A dyed fabric's resistance to losing or changing color in washing, light, rubbing (crocking) or perspiration.

CORE IDEAS

The story. In the Easter holiday of 1856, William Henry Perkin, eighteen years old and a student at the Royal College of Chemistry in London, was working in a makeshift laboratory at his family's home. His teacher, August Wilhelm von Hofmann, hoped chemists could make quinine, the malaria medicine, from coal tar, the black waste of gas works. Perkin's attempt gave only a black sludge. But when he washed it with a solvent, it gave a vivid purple solution that dyed silk beautifully and did not wash out. He patented it that summer, left college, and with his father and brother built a factory at Greenford, near London. Within two years mauve was the fashionable color of Europe.

How they figured it out. Perkin's real achievement was not luck alone but seeing what he had and then solving the practical problems: making aniline in quantity, purifying the dye, and learning to fix it on cotton as well as silk. His success launched a gold rush in coal-tar chemistry. Magenta followed in 1859, synthetic alizarin (madder's red) in 1869, and in 1880 Adolf von Baeyer worked out the synthesis of indigo, sold commercially from 1897. The dye industry built modern chemistry: much of what was learned making colors became the foundation of medicines, plastics and the synthetic fibers of Unit 3.

The fabric science. A dye must suit the fiber's chemistry. *Acid dyes* carry a negative charge; in an acidic bath, the amino groups of wool, silk and nylon become positively charged and hold them like magnets. *Basic dyes* carry a positive charge and suit acrylic. *Direct dyes* are long, flat molecules that cling to cellulose by many weak bonds; easy to use, but they fade in washing. *Fiber-reactive dyes*, introduced in 1956 by chemists at ICI, form a true covalent bond with cellulose's -OH groups, so they are very washfast; most bright cotton T-shirts use them. *Disperse dyes* are tiny and nearly insoluble; at high temperature, polyester's chains loosen and the dye dissolves into the fiber itself, which is why polyester must be dyed hot and why it is hard to dye at home. *Vat dyes*, like indigo, are reduced, absorbed and oxidized.

Why the label matters. All-purpose household dyes are a mixture of dye classes so they will color several fibers somewhat; that is why they give strong colors on cotton and wool but pale ones on polyester. A multifiber test strip, a ribbon woven with stripes of several fibers, shows at a glance which fibers a dye bath colors and which it leaves white.

The studio lab. You will dye a homemade multifiber strip (wool, silk or nylon, cotton, rayon, polyester and acrylic) in an acid dye bath made from food coloring and vinegar, a safe kitchen-chemistry acid dye. The result shows dye selectivity as clearly as any industrial test.

PICTURE STUDY



The Gobelins Dye Works (Teinture des Gobelins), Engraved for Diderot and d'Alembert's Encyclopédie, 1760s · Engraving · Published in the plates of the Encyclopédie; image from Wikimedia Commons, public domain
Image: [Wikimedia Commons](#), public domain

The Gobelins works in Paris dyed the wool and silk for France's royal tapestries, and their dyers were among the most skilled in Europe. This plate from the great French Encyclopédie shows the dye house: vats built over fires, workers lifting and wringing skeins, and the tools of the trade, a century before Perkin's purple.

Look closely

- Find the vats. How are they heated?
- Find a worker lifting or wringing skeins. What tools help him?
- Look at the numbered small drawings below the scene. Which tools would a dyer still use today?
- Find any ventilation or windows. Why would a dye house need them?

Talk about it

1. Every color here came from plants, insects or minerals. Which dyes from Lesson 6.1 might be in these vats?
2. Count the workers. How many people did it take to dye cloth by hand, and what dangers did they face?
3. What would change in this room after 1856?

Safety first. Dye with a parent present in dye-only equipment, wearing gloves and an apron. Food coloring and vinegar are mild, but the bath is hot: handle jars with a towel or tongs and let them cool before lifting out fiber. Commercial dye powders are fine dusts: a parent measures them, wearing a dust mask, and wipes up any spill wet.

STUDIO LAB

Dye Selectivity: The Multifiber Strip

Question: Which fibers does an acid dye color, and which does it leave unchanged? You will dye a homemade multifiber strip in a food-coloring acid bath and rate each fiber's uptake.

You will need

- Six 1 × 4 in strips: wool (or silk), nylon, cotton, rayon, polyester and acrylic, each labeled with a stitch of colored thread or a tag
- Liquid food coloring (red or blue), white vinegar, a quart canning jar used only for dyeing, a dye-only pot for a water bath, tongs and gloves
- A white card and the 1–5 color-rating scale from Lesson 6.1

Steps

1. **Hypothesis.** Predict which strips will dye deeply, lightly and not at all, and give a chemistry reason for each.
2. Stitch the six strips together side by side into one multifiber band with a running stitch along the top, so they all see the same bath.
3. Wet the band in warm water with a drop of soap for 15 minutes.
4. In the jar mix 2 cups of hot tap water, ¼ cup of vinegar and 20 drops of food coloring. Add the band.
5. Set the jar in the pot of water and heat gently so the jar's bath stays at about 85 °C (steaming) for 30 minutes. A parent supervises the stove.
6. Turn off the heat, let the jar cool, lift out the band with tongs, and rinse it until the water runs clear. Dry flat.
7. Rate each fiber's depth of color from 1 to 5. Photograph the band on a white card.
8. **Conclude.** Group the fibers by uptake and explain the groups with dye-class chemistry.
9. **Repeat round.** Dye a second band with no vinegar. Which fibers changed most, and why?

Tips

- The bath may “exhaust”: when the dye has all gone into the wool and nylon, the water turns nearly clear. That is acid dyeing working well.
- Cotton and rayon may pick up a faint tint that rinses away: food dyes are not fiber-reactive.
- Keep the band; it is a ready-made reference for identifying fibers by dyeability.

Check your work

- ☐ I dyed all six fibers in one bath so the test was fair.
- ☐ I rated uptake on a consistent scale and photographed the result.
- ☐ I explained the results with charges, amino groups and dye classes.

LAB NOTEBOOK

1. Make a table of dye classes: fiber(s), how they bond, fastness, an example use.
2. Tape in your multifiber band with each stripe labeled and rated.
3. Write a short timeline: 1856 mauve, 1859 magenta, 1869 alizarin, 1880/1897 indigo, 1956 reactive dyes.

KEY FORMULAS

$$\text{dye mass} = \text{fiber mass} \times \frac{\text{depth of shade (\%)}}{100}$$

$$\text{dye mass} = \text{fiber mass} \times 100 \text{depth of shade (\%)}$$

$$C_1V_1 = C_2V_2$$

$$C_1V_1 = C_2V_2$$

From history. Perkin sold his business in 1874, at thirty-six, to return to research, and was knighted in 1906, fifty years after his discovery. That same year chemists from around the world gathered to honor him, and the American chemical industry later established the Perkin Medal, still one of its highest awards.

WORKED EXAMPLES

Example 1. You want a 2% depth of shade on 150 g of cotton with a fiber-reactive dye. How much dye? If the dye is predissolved as a stock of 10 g per 100 mL, how many mL of stock?

Show solution

$$1. \text{Dye: } 150 \text{ g} \times 0.02 = 3 \text{ g} \quad 150 \text{ g} \times 0.02 = 3 \text{ g.}$$

$$2. \text{Stock concentration: } 0.1 \text{ g/mL} \quad 0.1 \text{ g/mL; volume } 3 \text{ g} \div 0.1 \text{ g/mL} = 30 \text{ mL} \quad 3 \text{ g} \div 0.1 \text{ g/mL} = 30 \text{ mL.}$$

Answer: 3 g of dye, or 30 mL of the stock solution.

Example 2. A 5% vinegar solution is diluted to make 2.0 L of dye bath at 0.5% acid. How much vinegar is needed?

Show solution

$$1. C_1V_1 = C_2V_2 \Rightarrow 5\% \times V_1 = 0.5\% \times 2.0 \text{ L} \quad C_1V_1 = C_2V_2 \Rightarrow 5\% \times V_1 = 0.5\% \times 2.0 \text{ L.}$$

$$2. V_1 = \frac{0.5 \times 2.0}{5} \text{ L} = 0.20 \text{ L} = 200 \text{ mL} \quad V_1 = 50.5 \times 2.0 \text{ L} = 0.20 \text{ L} = 200 \text{ mL.}$$

Answer: 200 mL of vinegar, made up to 2.0 L with water.

Example 3. A depth-of-shade series dyes five 10 g cotton swatches at 0.25, 0.5, 1, 2 and 4 percent. How much dye does each need, and how much in total?

Show solution

$$1. 10 \times 0.0025 = 0.025 \text{ g} \quad 10 \times 0.0025 = 0.025 \text{ g; } 0.05 \text{ g; } 0.1 \text{ g; } 0.2 \text{ g; } 0.4 \text{ g.}$$

$$2. \text{Total: } 0.025 + 0.05 + 0.1 + 0.2 + 0.4 = 0.775 \text{ g} \quad 0.025 + 0.05 + 0.1 + 0.2 + 0.4 = 0.775 \text{ g.}$$

Answer: 0.025 to 0.4 g each, 0.775 g in all. Each step doubles the dye; the shades will not look twice as dark, because the eye judges color on a roughly logarithmic scale.

PRACTICE

1. **Easy** How old was Perkin when he discovered mauveine, and what was he trying to make?

Show answer

Eighteen; quinine.

2. **Easy** Which dye class suits polyester?

Show answer

Disperse dyes.

3. **Easy** Which dye class forms a covalent bond with cotton?

Show answer

Fiber-reactive dyes.

4. **Medium** How much dye for a 3% shade on 80 g of wool?

Show answer

2.4 g.

5. **Medium** Dilute 50 mL of a 2% stock to half that concentration. What final volume?

Show answer

100 mL.

6. **Medium** Why do acid dyes color wool and nylon but not cotton?

Show answer

In acid, the amino groups of wool and nylon become positive and attract negative acid dye ions; cellulose has no such groups.

7. **Medium** Why do all-purpose dyes give pale colors on polyester?

Show answer

They contain mostly acid and direct dyes, which polyester cannot hold; polyester needs disperse dyes at high temperature.

8. **Hard** A 4% shade needs 6 g of dye. What mass of fiber is being dyed?

Show answer

150 g.

9. **Hard** From 250 mL of a 10% stock, how much water must be added to make a 2% solution?

Show answer

Final volume 1,250 mL; add 1,000 mL.

10. **Hard** Explain how the dye industry helped build modern chemistry and medicine.

Show answer

Coal-tar dye research trained chemists, built laboratories and companies, and developed synthesis methods later used for drugs (some early medicines came from dye chemistry), plastics and synthetic fibers.

11. **Challenge** Perkin's failure to make quinine became a success. Using his story, explain the difference between luck and discovery, and name one habit that turned his accident into an industry.

Show answer

Luck gave him an unexpected purple; discovery came from noticing it, testing whether it dyed and lasted, and solving manufacturing and fixing problems. Habits: careful observation, curiosity about "failures," and persistence in practical development.

COMMON MISTAKES

- Expecting one dye to color every fiber. Match the dye class to the fiber.
- Dyeing a polyester-cotton blend with all-purpose dye and expecting a solid color. The polyester stays pale and the blend looks heathered.
- Measuring dye on wet fiber weight. Use dry weight.

Make it a game · Which Fiber Took the Dye? Lay out the dyed multifiber bands (yours and any extra) with the labels hidden. Players race to name each stripe's fiber from its color depth alone, then confirm with a feel test. One point per correct call; three bonus points to anyone who can explain the polyester stripe using the word disperse.

Scripture. "She is not afraid of the snow for her household: for all her household are clothed with scarlet." (Proverbs 31:21, KJV)

Scarlet cloth in the ancient world was dyed with costly insect dyes, often on warm wool. The capable woman's care for her household shows in the quality of what she provides.

6.3 PRINTING CLOTH: BLOCKS, ROLLERS AND SCREENS

OBJECTIVES

- Describe block printing, copperplate and roller printing, and screen printing and the history of printed cottons from India to Jouy.
- Explain full-drop and half-drop repeats and how printers register colors.
- Carve a block, plan a repeat and print a tea towel, calculating repeats and paint coverage.

Warm-up. Find a printed fabric in your house (a curtain, a shirt, a pillowcase). Find one motif and trace your finger to the next identical motif across and down. Measure both distances. Is the second motif directly below the first, or shifted?

WATCH

Let's Learn About...Block Printing!

[Asian Civilisations Museum](#) · 6:12

<https://www.youtube.com/watch?v=7WPI4dcnmTc>

WHEN TO WATCH

After “How they figured it out.” Watch how the printer loads and places each block, then try the printing method shown at the end.

BACKUP VIDEO

How was it made? Screenprinting

[Victoria and Albert Museum](#) · 3:04

<https://www.youtube.com/watch?v=zNCyd0Usglc>

A museum printer shows screen printing: one screen, one color, one pull.

KEY TERMS

block printing

Printing cloth by pressing a carved, inked wooden block onto it, one impression at a time, one block per color.

roller printing

Printing with engraved copper cylinders that pick up dye and print continuously; patented by Thomas Bell in 1783.

repeat

The distance a printed pattern travels before it starts over, measured across (horizontal repeat) and along (vertical repeat) the cloth.

calico and chintz

Printed and painted cottons from India (calico from Calicut); chintz was often glazed and brightly colored.

screen printing

Pushing dye or paint through a fine mesh screen with a stencil, one screen per color; rotary screens print continuously.

half-drop

A repeat in which each column of motifs is shifted down by half the vertical repeat, so motifs form a diagonal network instead of a grid.

CORE IDEAS

The story. For centuries the most wonderful cottons in the world came from India: fine calicoes and brilliant chintzes, block-printed and hand-painted with mordants and dyes that stayed bright through washing, a skill Europeans could not match. When the East India companies brought them to Europe in the 1600s, they were so popular that France banned printed cotton imports from 1686 to 1759, and England passed laws in 1700 and 1720 to protect its wool and silk weavers. When the French ban was lifted, Christophe-Philippe Oberkampf, a German-born printer, opened a works at Jouy-en-Josas near Versailles in 1760. His “toiles de Jouy” became famous, and in 1783–84 his designer Jean-Baptiste Huet drew a toile showing the factory's own work: printing, washing, bleaching and inspecting.

How they figured it out. Block printing is slow: a skilled printer stamps the cloth by hand, lining up each impression with pins on the block's corners. Copperplate printing (from the 1750s) used large engraved plates for fine, one-color scenes like Jouy's. Then in 1783 the Scotsman Thomas Bell patented roller printing: engraved copper cylinders, each inked by a trough and wiped by a blade, printing yard after yard continuously, one roller per color. A roller press could do the work of dozens of block printers. In the

twentieth century, screen printing (dye pressed through a mesh stencil) took over, first by hand on long tables and then, from the 1960s, with rotary screens.

The fabric science. A print is only as good as its fixing. Indian dyers printed mordants, not dyes, and then dyed the whole cloth, so color stuck only where mordant had been printed; the same chemistry from Lesson 6.1. Modern prints use either dyes (which penetrate the fiber and must be fixed by steam or heat) or pigments (insoluble color glued to the surface with a binder, cured by heat). Pigment prints are simple but stiffen the cloth slightly and can crock (rub off). Every print also needs a plan: a repeat that tiles across the width and down the length so the seams between impressions vanish, and registration, so that each color lands exactly where it should.

Repeats. In a full-drop (block) repeat, motifs sit in straight rows and columns. In a half-drop, every other column drops by half the vertical repeat, which hides the grid and makes the pattern flow diagonally. Printers measure the horizontal repeat to know how many fit across the fabric's width, and designers choose repeats that divide evenly into it.

The studio lab. You will carve a simple block from an eraser or foam, plan a half-drop repeat on paper, and print a cotton tea towel with fabric paint, heat-setting it so it survives washing. Then you will test whether it does.

PICTURE STUDY



Les Travaux de la Manufacture (The Work of the Factory), Designed by Jean-Baptiste Huet; printed by the Oberkampf manufactory, Jouy-en-Josas, 1783–84 · Copperplate-printed cotton (toile de Jouy) · The Metropolitan Museum of Art, New York

Image: [Wikimedia Commons](#), public domain

This is a printed cloth about printing cloth. Huet drew Oberkampf's own works at Jouy: block printers at their tables, copperplate presses, washers in the river and long lengths of cotton laid out on the grass to bleach. It was printed in one color from engraved copper plates, the method that made the famous toiles de Jouy.

Look closely

- Find a block printer at work. What is in his hand, and what is on the table?
- Find the copperplate press. How is it turned?
- Find the cloth laid out on the field. Which finish is happening there?
- Find a vignette that repeats. How far is it from its twin? That is the repeat.

Talk about it

1. Why might a factory choose to print a picture of itself and sell it?
2. How many separate trades can you count on this one cloth?
3. This toile was printed in one color. How would printing it in four colors with blocks change the work?

Safety first. Carve blocks with a lino cutter or craft knife only with a parent present, cutting away from your body and your holding hand, with the block on a bench hook or non-slip mat. Use fabric paint in a ventilated room and keep it off skin. Heat-set prints with an iron on its upright rest when not in use, and unplug it afterward.

STUDIO LAB

A Block-Printed Tea Towel in Half-Drop

Question: Can you plan and print a half-drop repeat so the seams between impressions disappear, and will your print survive washing? You will carve, plan, print, heat-set and test.

You will need

- A plain cotton or linen tea towel (prewashed, no fabric softener), about 18 × 28 in
- A large rubber eraser, a block of craft foam glued to wood, or a soft-cut printing block; a lino cutter or craft knife
- Fabric paint (textile medium), a foam brush or brayer, a tray, newspaper, chalk or a washable marker, a ruler and graph paper
- An iron and a press cloth

HALF-DROP BLOCK-PRINTED TEA TOWEL

Finished size: One towel about 18 × 28 in with about 48 impressions · About 3 hours, plus drying and heat setting

Fabric and notions

- One prewashed cotton or linen tea towel
- A carving block about 2 × 2½ in
- About 5 mL of fabric paint in one color (10 mL for two colors)

How to make it

1. Draw a simple motif (a leaf, a star, a sheep) on paper that fits the block, with a little space around it. Transfer it to the block reversed.
2. Carve away everything that should not print, cutting away from your hands. Test-stamp on scrap paper and fix any gaps.
3. Plan the repeat on graph paper to scale: columns 2½ in apart, rows 3 in apart, alternate columns dropped 1½ in.
4. Press the towel and lay it on a padded table (newspaper under an old sheet). Mark the column lines and the first impression of each column lightly with chalk.
5. Load the block thinly and evenly with the brayer. Press it straight down, hold, and lift straight up. Reload for every impression or every second one.
6. Work column by column, following your chalk marks. Let the paint dry 24 hours.
7. Heat-set by ironing on the back with a press cloth, at the cotton setting, 3–5 minutes per area, keeping the iron moving.

Fabric check: Use 100% cotton or linen, prewashed with no softener, so paint can bond; synthetic towels repel paint and can melt under a cotton-setting iron. A smooth, tight weave prints crisply; terry cloth does not. An old pillowcase is a good practice piece.

Steps

1. **Hypothesis.** Predict how much your print will fade after five washes, and whether a half-drop will hide your small alignment errors better than a full drop.
2. Calculate repeats across and down, total impressions and paint needed before you start.
3. Print a full-drop test strip and a half-drop test strip on scrap cloth. Compare how visible the grid is.
4. Print the towel following the pattern card. Record any impressions that misprinted and why.
5. Heat-set, then cut or mark a small test corner. Photograph the towel.
6. **Wash test.** Wash the towel (or a printed scrap) five times with regular laundry and compare photos. Rub a white cloth hard on a dry print ten times: does color crock off?
7. **Conclude.** Did the half-drop hide errors? Did the print hold? What would you change?

8. **Repeat round.** Print a second towel or scrap with a second color registered on top of the first, using corner marks.

Tips

- Thin paint prints crisply; thick paint smears. Roll the block until the paint looks like velvet, not like jam.
- Print one test impression on scrap after every reload.
- A towel printed for someone else (a grandparent, a neighbor) is a gift with your name on it.

Check your work

- ☐ I planned and calculated the repeat before printing.
- ☐ I printed a regular half-drop with consistent impressions and heat-set it properly.
- ☐ I tested the print's wash and rub fastness and recorded the results honestly.

LAB NOTEBOOK

1. Draw your repeat plan to scale, labeling horizontal repeat, vertical repeat and half-drop offset.
2. Tape in your test strips (full drop and half drop) and a paper proof of your block.
3. Sketch the three printing methods (block, roller, screen) with one sentence each on speed and use.

KEY FORMULAS

$$\text{repeats across} = \left\lfloor \frac{\text{printable width}}{\text{horizontal repeat}} \right\rfloor$$

$$\text{repeats across} = \lfloor \text{horizontal repeat} \text{ printable width} \rfloor$$

$$\text{half-drop offset} = \frac{\text{vertical repeat}}{2}$$

$$\text{half-drop offset} = 2 \text{vertical repeat}$$

From history. Oberkampf's works became one of the largest factories in France, and Louis XVI granted it the title of royal manufactory in 1783. Napoleon later visited and awarded Oberkampf the Legion of Honor. Toile de Jouy designs are still reprinted today.

WORKED EXAMPLES

Example 1. A tea towel is 18 in wide with $\frac{3}{4}$ -in hems on each side. Your block prints a motif with a $2\frac{1}{2}$ -in horizontal repeat and a 3-in vertical repeat. How many motifs fit across, and how many rows in 26 in of printable length? Total impressions?

Show solution

1. Printable width: $18 - 2 \times 0.75 = 16.5$ in $18 - 2 \times 0.75 = 16.5$ in; across $\lfloor 16.5 \div 2.5 \rfloor = 6$ $\lfloor 16.5 \div 2.5 \rfloor = 6$.
2. Rows: $\lfloor 26 \div 3 \rfloor = 8$ $\lfloor 26 \div 3 \rfloor = 8$.
3. Impressions: $6 \times 8 = 48$ $6 \times 8 = 48$.

Answer: 6 across and 8 rows, 48 impressions (a half-drop would trim a half motif at the top or bottom of alternate columns).

Example 2. In a half-drop with a 3-in vertical repeat, how far down does each alternate column start? If the first column's motifs sit at 0, 3, 6 ... in, where do the second column's sit?

Show solution

1. Offset: $3 \text{ in} \div 2 = 1.5$ in $3 \text{ in} \div 2 = 1.5$ in.
2. Second column: 1.5, 4.5, 7.5, ... in 1.5, 4.5, 7.5, ... in.

Answer: $1\frac{1}{2}$ in down; second-column motifs at $1\frac{1}{2}$, $4\frac{1}{2}$, $7\frac{1}{2}$ in, and so on.

Example 3. Fabric paint covers about 40 square inches per mL when stamped. Each impression covers about 2.4 in² of solid color. How much paint for 48 impressions, with 50% extra for loading the block?

Show solution

1. Area: $48 \times 2.4 = 115.2 \text{ in}^2$ $48 \times 2.4 = 115.2 \text{ in}^2$.

2. Paint: $115.2 \div 40 = 2.9 \text{ mL}$ $115.2 \div 40 = 2.9 \text{ mL}$; with 50% extra $\approx 4.3 \text{ mL} \approx 4.3 \text{ mL}$.

Answer: About 4–5 mL, a teaspoon, on these assumptions: a small jar prints many towels.

PRACTICE

1. Easy Where did calico and chintz come from?

Show answer

India (calico from Calicut).

2. Easy Who patented roller printing, and when?

Show answer

Thomas Bell, 1783.

3. Easy What is a half-drop repeat?

Show answer

A repeat in which alternate columns are shifted down half the vertical repeat.

4. Medium How many 4-in repeats fit across 44 in of fabric?

Show answer

11.

5. Medium A pattern's vertical repeat is 27 in. What is the half-drop offset?

Show answer

13½ in.

6. Medium How did Indian dyers make printed colors washfast?

Show answer

They printed mordants (and resists) on the cloth and then dyed it, so the dye bonded only where the mordant was.

7. Medium Give one advantage and one disadvantage of pigment printing compared with dye printing.

Show answer

Advantage: simple, works on any fiber, no washing out of excess dye. Disadvantage: sits on the surface, can stiffen the cloth and crock.

8. **Hard** A 54-in-wide fabric has 1 in of selvage each side not printed. A designer wants a whole number of repeats across. Which repeat widths between 5 and 7 in work exactly?

Show answer

Printable 52 in: $52 \div 6.5 = 8$ works; also 5.2 in (10 repeats) and 5.77 in (9). A clean answer: 6½ in.

9. **Hard** A roller press prints 60 yd an hour; a block printer prints about 1.5 yd an hour for a two-color design. How many block printers equal one press?

Show answer

40.

10. **Hard** Why did France and England ban or restrict printed cotton imports, and what happened after the bans ended?

Show answer

To protect their wool and silk weavers from wildly popular Indian cottons. After the French ban ended in 1759, European printers such as Oberkampf at Jouy built their own industry.

11. **Challenge** Design a two-color block print for a tea towel. Describe the two blocks, how you will register the second color, the repeat type, and the number of impressions for an 18 × 28 in towel.

Show answer

A good answer names a base block and an accent block, describes registration marks or corner pins, chooses full-drop or half-drop with measured repeats, subtracts hems, and calculates impressions for each block (they may differ if the accent is used on alternate motifs).

COMMON MISTAKES

- Carving the motif unreversed. Letters and asymmetric shapes print backward unless reversed on the block.
- Overloading the block. Too much paint fills the fine lines.
- Skipping heat setting. Unset fabric paint washes out.

Make it a game · Find the Repeat. A parent holds up printed fabrics (curtains, shirts, wrapping paper) one at a time. The first player to point to two identical motifs and call out “full drop” or “half drop” scores a point; a correct measured repeat (within ½ in) adds a bonus. Play until everyone has found five.

6.4 FINISHES: SANFORIZING, PERMANENT PRESS AND FIRE SAFETY

OBJECTIVES

- Describe how preshrinking (Sanforizing), wrinkle-resistant (durable press), water-repellent and flame-resistant finishes work.
- Tell the story of Ruth Benerito's work on wrinkle-resistant cotton and of the Triangle Shirtwaist fire as fire-safety history.
- Test finished and unfinished fabrics for shrinkage, wrinkle recovery and water repellency and calculate the results.

Warm-up. Find a dress shirt or pair of pants with a label that says non-iron, wrinkle-free, easy care, preshrunk or Sanforized. Crumple the cuff and a plain cotton handkerchief in your fists for 30 seconds. Which recovers better?

WATCH

Ruth Benerito - Cotton Research and Promotion Program Hall of Fame

Cotton Facts · 3:13

<https://www.youtube.com/watch?v=UtSdDv-m0E8>

WHEN TO WATCH

After “How they figured it out.” Listen for the problem Benerito's team set out to solve and how their chemistry solved it.

BACKUP VIDEO

How FR Fabrics are Tested

WorkriteFR · 3:21

https://www.youtube.com/watch?v=uyDaUsrc_Po

Watch how flame-resistant fabrics are tested in a laboratory before they can be sold.

KEY TERMS

finish

Any treatment that changes a fabric's appearance, hand or performance after it is woven or knitted.

durable press

A finish that cross-links cellulose chains so cotton resists wrinkling and holds pressed creases through washing; also called permanent press or wrinkle-resistant.

flame resistant

A fabric or finish that resists ignition and stops burning when the flame is removed.

Sanforizing

A compressive preshrinking process, patented by Sanford L. Cluett in 1930, that squeezes cloth lengthwise between a rubber belt and a heated cylinder so it will not shrink much later.

water repellent

A finish that makes water bead and roll off the fibers while leaving spaces for air; different from waterproof, which blocks water completely with a coating or film.

residual shrinkage

The shrinkage a fabric still has left after finishing; low residual shrinkage is the goal of preshrinking.

CORE IDEAS

The story. Two very different stories show why finishes matter. On March 25, 1911, a fire broke out on the eighth floor of the Asch Building in New York, home of the Triangle Waist Company, which made women's blouses (shirtwaists). Bins of cotton scraps fed the flames; one exit door was locked, the single fire escape collapsed, and fire ladders could not reach the upper floors. One hundred forty-six workers, most of them young women, many newly arrived from Italy and Eastern Europe, died. New York responded with a commission whose reforms brought fire drills, sprinklers, unlocked exits and safer factories, and those rules shaped fire codes across the country. Forty years later, in 1953, Congress passed the Flammable Fabrics Act after deaths from dangerously flammable sweaters and costumes, and today children's sleepwear must meet strict flammability standards.

How they figured it out. The second story is quieter. In the 1950s and 1960s, Ruth Benerito, a chemist at the U.S. Department of Agriculture's Southern Regional Research Center in New Orleans, led work on making cotton behave better. Cotton wrinkles because its chains slide and hydrogen-bond in new places when bent wet (Unit 1). Benerito's team developed and improved ways of linking

neighboring cellulose chains with small chemical bridges (cross-links) so they spring back to where they were set. Cotton shirts that came out of the dryer smooth, wash-and-wear cotton, helped cotton compete with polyester. She received many patents and, in 2002, the Lemelson-MIT Lifetime Achievement Award.

The fabric science. *Preshrinking*: woven cotton is stretched lengthwise in manufacture, and in its first washes it relaxes and shrinks. Sanford Cluett's 1930 process mechanically compresses the cloth lengthwise while damp and hot, so it has little shrinkage left; "Sanforized" on a label promised residual shrinkage of about 1 percent. *Durable press* cross-links make cotton recover from wrinkles, at some cost to strength and abrasion resistance. *Water repellents* (waxes, silicones and fluorochemicals) coat each fiber with a low-energy surface so water beads into round drops instead of spreading; the fabric still breathes. *Flame-resistant* finishes and fibers either release water or gases that interrupt burning or form a protective char; wool and some synthetics are naturally harder to ignite than cotton or rayon.

Fairly stated. Every finish is a trade-off. Wrinkle-resistant cotton is a little weaker; water repellents wear off and must be renewed; some old finishing chemicals have been replaced as their effects became better understood. A careful sewer reads labels, prewashes fabric that is not preshrunk, and chooses finishes for the job.

The studio lab. You will run three finish tests side by side: shrinkage (a preshrunk or Sanforized cotton against an untreated muslin), wrinkle recovery (a non-iron shirt fabric against plain cotton) and water repellency (cotton you treat yourself with beeswax against untreated cotton), measuring each property with numbers.

PICTURE STUDY



View of the Plain of Haarlem with Bleaching Grounds, Jacob van Ruisdael, c. 1670s · Oil on canvas · Image from Wikimedia Commons, public domain
Image: [Wikimedia Commons](#), public domain

Bleaching was one of the oldest finishes. Around Haarlem, linen from all over Europe was soaked in lye and buttermilk and laid in long strips on the grass for weeks so that sun, air and moisture would whiten it. Ruisdael painted the bleaching fields again and again beneath a vast Dutch sky.

Look closely

- Find the long white strips on the fields. What are they, and why are they laid out flat?
- Find the workers among them. What might they be doing?
- Look at the sky. How much of the painting is sky, and why would weather matter to a bleacher?
- Find the great church on the horizon. Why might Ruisdael include it?

Talk about it

1. Sunlight and moisture slowly break down colored impurities in linen. What would happen to the cloth if it rained for a week, or if the bleachers left it out too long?
2. Bleaching took weeks in Ruisdael's day; chemical bleaches made it hours by the 1800s. What trade-offs might that bring?
3. Which finish from this lesson would a Haarlem linen merchant have most wanted to invent?

Safety first. The beeswax treatment uses a hair dryer or a warm iron with a press cloth; keep the iron on its upright rest, unplug it afterward and never leave it on unattended. Do not apply aerosol water-repellent sprays indoors; if you use one, a parent applies it outdoors. Never test flame resistance yourself on a garment: the burn tests in this course use only small snippets with a parent beside you.

STUDIO LAB

Three Finish Tests

Question: How much difference do preshrinking, a wrinkle-resistant finish and a water-repellent treatment really make? You will test each against an untreated control and measure the results.

You will need

- Unwashed cotton muslin and a preshrunk or Sanforized cotton (check bolt labels), about $\frac{1}{4}$ yd each
- A scrap from a non-iron dress shirt and a plain cotton shirting of similar weight
- Two 6 × 6 in squares of plain cotton, a block of beeswax, a hair dryer, a spray bottle and a timer
- A permanent marker, a metric ruler, the crease-test kit from Lesson 1.4 (weight, protractor, index cards)

Steps

1. **Hypothesis.** Predict the shrinkage of each cotton, the wrinkle recovery angles, and the spray-test ratings.
2. **Shrinkage.** Mark a 50 × 50 cm square on each cotton (lengthwise and crosswise). Wash both three times hot and tumble dry. Measure and calculate length and width shrinkage.
3. **Wrinkle recovery.** Cut three 1 × 3 in strips from each shirting and run the Lesson 1.4 crease test (500 g for 5 minutes, then 5 minutes recovery). Calculate the mean recovery angle and percent.
4. **Water repellency.** Rub beeswax firmly over one cotton square, then warm it with the hair dryer until the wax melts into the fibers. Leave the other square untreated.
5. Hold each square at 45° and spray it with ten pumps from 6 in away. Rate 0–100 by how much of the surface wetted. Also time how long a single dropped bead takes to soak in (stop at 3 minutes). Repeat three times.
6. Wash the waxed square once in cool water and repeat the spray test. How durable was the finish?
7. **Conclude.** Rank the three finishes by how large an effect they had. Which would you most want on a garment you sew?
8. **Repeat round.** Prewash a new piece of the muslin and sew a small bag from it. Then wash it three times. Did prewashing prevent the puckers you would expect?

Tips

- Draw the 50 cm marks with a ruler on a flat table; a slanted line makes width and length errors.
- Beeswax cotton is the old way of making waxed canvas and food wraps: stiff when cold, supple when warm.
- Keep all your test pieces; the unit project uses them.

Check your work

- ☐ I ran each finish test against an untreated control with only the finish changed.
- ☐ I calculated shrinkage, recovery and spray ratings correctly.
- ☐ I described one trade-off I observed for each finish.

LAB NOTEBOOK

1. Draw cotton chains before and after cross-linking, showing how cross-links pull them back.
2. Draw a water drop on untreated and on repellent-treated fabric, showing spreading versus beading.
3. Write a short fire-safety checklist for a sewing room or small workshop, inspired by the lessons of 1911.

KEY FORMULAS

$$\text{shrinkage} = \frac{L_0 - L}{L_0} \times 100\%$$

$$\text{shrinkage} = \frac{L_0 - L}{L_0} \times 100\%$$

$$\text{cut length} = \frac{\text{finished length}}{1 - \text{shrinkage as a decimal}}$$

$$\text{cut length} = \frac{\text{finished length}}{1 - \text{shrinkage as a decimal}}$$

From history. Ruth Benerito (1916–2013) grew up in New Orleans and earned her doctorate in chemistry at the University of Chicago while teaching. She spent most of her career at the USDA laboratory in New Orleans and later taught at the University of New Orleans, and she was inducted into the National Inventors Hall of Fame in 2008.

WORKED EXAMPLES

Example 1. A 50.0 cm mark on unshrunk muslin measures 46.5 cm after three hot washes; on Sanforized cotton it measures 49.6 cm. Find each shrinkage.

Show solution

$$1. \text{ Muslin: } \frac{50.0 - 46.5}{50.0} \times 100\% = 7\%$$

$$2. \text{ Sanforized: } \frac{50.0 - 49.6}{50.0} \times 100\% = 0.8\%$$

Answer: 7% against 0.8%: the finish did its job.

Example 2. You must make curtains 84 in long from a cotton that shrinks 5% lengthwise, and you will not prewash. How long must you cut them (before hems)?

Show solution

$$1. \frac{84 \text{ in}}{1 - 0.05} = \frac{84}{0.95} = 88.4 \text{ in} - 0.0584 \text{ in} = 0.9584 = 88.4 \text{ in.}$$

Answer: About 88½ in. Better still, prewash the fabric and cut 84 in plus hems.

Example 3. In the spray test, water is sprayed on a fabric and rated 0 (fully wetted) to 100 (no wetting). Three trials on waxed cotton give 80, 90 and 80; untreated cotton gives 0, 0 and 50. Find each mean.

Show solution

$$1. \text{ Waxed: } \frac{80 + 90 + 80}{3} = 83.3$$

$$2. \text{ Untreated: } \frac{0 + 0 + 50}{3} = 16.7$$

Answer: Means of about 83 and 17. The untreated sample's one 50 was likely surface sizing; repeat the test after a wash.

PRACTICE

1. **Easy** Who patented Sanforizing, and in what year?

Show answer

Sanford L. Cluett, 1930.

2. **Easy** What is the difference between water repellent and waterproof?

Show answer

Water repellent makes water bead off while the fabric breathes; waterproof blocks water entirely with a coating or film.

3. **Easy** In what year was the Triangle Shirtwaist fire, and name two safety failures.

Show answer

1911; a locked exit door and a fire escape that collapsed (also ladders that could not reach, flammable scraps).

4. **Medium** A 40 cm mark shrinks to 38.2 cm. Find the shrinkage.

Show answer

4.5%.

5. **Medium** Fabric shrinks 3%. What length must be cut for 60 in finished?

Show answer

$60/0.97 \approx 61.9$ in $60/0.97 \approx 61.9$ in

6. **Medium** How does a durable-press finish keep cotton from wrinkling?

Show answer

It forms chemical cross-links between cellulose chains, so they spring back to their set positions instead of re-bonding in new ones.

7. **Medium** Give one trade-off of wrinkle-resistant finishes.

Show answer

Reduced tear and abrasion strength (also stiffer hand or reduced absorbency).

8. **Hard** A shirt pattern needs 32 in of fabric length; the fabric shrinks 6% unwashed. How much fabric length is used if you do not prewash, and what happens to a shirt cut at 32 in?

Show answer

$32/0.94 \approx 34$ in $32/0.94 \approx 34$ in; a shirt cut at 32 in would shrink to about 30 in, two inches short.

9. **Hard** Why does Mark 2:21 apply to a garment of non-preshrunk cotton as well as to wool?

Show answer

Any unshrunk new cloth shrinks in its first washes; sewn onto an already-shrunk garment, it pulls and tears it.

10. **Hard** List three fire-safety reforms that followed the Triangle fire and one modern place you can see them.

Show answer

Fire drills, sprinkler systems, unlocked and marked exits (also fire escapes and occupancy limits); visible in any school or store with lit exit signs and sprinklers.

11. **Challenge** Design a finish plan for a child's rain jacket: name the finishes, what each does, and one trade-off for each.

Show answer

For example: water-repellent finish (beads rain; must be renewed), a waterproof coated or laminated layer at seams (blocks water; less breathable), preshrinking (stable size; small cost), and choosing an inherently flame-resistant or properly tested fabric (safety; cost). Credit for sound reasoning.

COMMON MISTAKES

- Assuming every cotton is preshrunk. Read the bolt; when in doubt, prewash.
- Calling a water-repellent jacket waterproof. In a downpour it will wet through at seams and pressure points.
- Treating the Triangle fire as only a sad story. It is also the reason for exits and sprinklers that protect people today.

Make it a game · Label Detectives. Players race through the closet for labels that mention a finish: preshrunk, wrinkle-free, non-iron, water repellent, stain resistant, flame resistant (on a child's pajamas). Score one point per finish found and two if you can explain how it works. Then crumple the shirts you found and see which finish proves itself.

6.5 CARE LABELS AND THE CHEMISTRY OF STAINS

OBJECTIVES

- Explain the U.S. Textile Fiber Products Identification Act and the FTC Care Labeling Rule and read every care symbol.
- Explain how surfactants, enzymes and oxidizing bleaches remove different kinds of stains, and why hot water sets protein stains.
- Run a controlled stain-removal and colorfastness lab and rate results on a scale.

Warm-up. Choose five garments and read their care labels aloud. Draw each symbol you find. Which symbols can you already read, and which are a mystery?

WATCH

How To Read The Care Label - Care Label Symbols Explained

Jeeves NY · 3:26

<https://www.youtube.com/watch?v=Ux30YueXA08>

WHEN TO WATCH

After “How they figured it out.” Pause at each symbol family and say its meaning before the presenter does.

BACKUP VIDEO

How Detergents Works: Surfactants

cleaninstitute · 1:15

<https://www.youtube.com/watch?v=F7-ie4uWX04>

A short animation of how a surfactant lifts oil off fabric.

KEY TERMS

Care Labeling Rule

A Federal Trade Commission rule, first issued in 1971, requiring most clothing sold in the United States to carry permanent care instructions for at least one safe method of cleaning.

surfactant

A molecule with a water-loving head and an oil-loving tail; surfactants surround oily soil in micelles so water can carry it away.

oxidizing bleach

Chlorine bleach (sodium hypochlorite) or oxygen bleach (hydrogen peroxide, sodium percarbonate), which break the color-producing parts of stain molecules.

Textile Fiber Products Identification Act

A 1958 U.S. law (effective 1960) requiring labels to name each fiber by its generic name and percentage by weight, the maker or seller, and the country of origin.

enzyme

A protein catalyst in detergents that breaks down specific stains: proteases attack proteins (blood, egg), amylases starch, lipases fats.

crocking

The transfer of color from a fabric by rubbing.

CORE IDEAS

The story. Until the 1950s a shopper often could not tell what a garment was made of. New fibers with trade names multiplied, and some sellers passed off cheaper fibers as costlier ones. In 1958 Congress passed the Textile Fiber Products Identification Act, requiring generic fiber names and percentages on labels. Then in 1971 the Federal Trade Commission issued the Care Labeling Rule, after years of ruined clothes and complaints, requiring permanent labels with at least one safe cleaning method. In 1997 the U.S. began allowing standard care symbols in place of words. Every label you read in Lesson 6.5's warm-up is the product of those rules.

How they figured it out. Laundry is chemistry. Soap, made from fats and lye since ancient times, is a surfactant: its long molecules have a charged head that loves water and an oily tail that loves grease. In wash water the tails bury themselves in oily soil and the heads face outward, forming tiny balls called micelles that float away. Modern detergents use synthetic surfactants that work in hard

water, plus enzymes, first added widely in the 1960s, that digest specific stains, and oxygen bleaches that whiten. The chemist's rule is to match the treatment to the stain.

The fabric science. Stains fall into families. *Protein stains* (blood, egg, milk, grass contains some): rinse in *cold* water first, because heat cooks proteins onto the fiber, as heat sets an egg; then use an enzyme detergent. *Oily stains* (butter, salad dressing, collar grime): surfactant concentrated on the spot, and warm water. *Tannin stains* (tea, coffee, fruit juice): rinse, then oxygen bleach; avoid soap first on fruit, which can set it. *Dye stains* (marker, a red sock's bleed): treat quickly; may need oxygen bleach or color remover. Combination stains (chocolate, ketchup) need steps in order: protein and starch first, then oil, then color. Always test on a hidden spot, never dry a stain in a hot dryer until it is gone, and never mix chlorine bleach with ammonia, vinegar or other cleaners.

Reading symbols. Five families: the washtub (washing; dots for temperature, a hand for hand wash, bars under it for gentler cycles), the triangle (bleach; crossed out for none, with two lines for non-chlorine only), the square (drying; a circle inside for tumble dry, lines for line or flat drying), the iron (dots for heat), and the circle (professional cleaning). An X through any symbol means do not.

The studio lab. You will stain matching cotton swatches with five common stains, let them set, and treat them by four methods (cold water, hot water, plain detergent, enzyme detergent), rating each result on a 1-to-5 scale. A colorfastness test on two dyed garments finishes the lab.

PICTURE STUDY



The Washerwoman, Jean-Siméon Chardin, c. 1733–39 · Oil on canvas · Nationalmuseum, Stockholm (versions also in other museums)

Image: [Wikimedia Commons](#), public domain

Chardin painted the quiet work of Paris households with great respect. A laundress leans over her wooden tub, her arms in the water, and looks up as if someone has spoken to her. Laundry was heavy, constant work: water hauled and heated, linen soaked, scrubbed, rinsed and hung to dry.

Look closely

- Find the tub. What is it made of, and what is it standing on?
- Look at the laundress's sleeves and apron. How has she dressed for the work?
- Find the laundry hanging on the ladder and the basin on the chair. What stage of the work is each?
- Find the cat. What does it add to the scene?

Talk about it

1. Chardin's laundress had soap, water and sunlight but no enzymes or care labels. Which stains from this lesson could she remove, and which would defeat her?
2. How many hours a week do you think one household's laundry took in 1735?
3. Why might Chardin think such ordinary work worth painting?

Safety first. Use only detergents, enzyme detergent and oxygen bleach for this lab; if a parent uses chlorine bleach, it is never mixed with anything else and is used with gloves and ventilation. Keep all cleaning products labeled and out of reach of young children. Wear gloves when hands will be in detergent solutions for a long time.

STUDIO LAB

The Stain Lab and a Colorfastness Check

Question: Which treatment removes each kind of stain best, and does water temperature matter? You will stain identical cotton swatches, treat them four ways, and rate the results; then check two garments for colorfastness.

You will need

- Twenty 4 × 4 in swatches of the same white cotton (an old sheet), labeled with a laundry marker
- Five stains: egg yolk or milk (protein), cooking oil or butter (oil), strong tea (tannin), ketchup or chocolate (combination), a washable marker (dye)
- Plain liquid detergent (no enzymes, if you can find one) and an enzyme (“bio”) detergent, oxygen bleach, measuring spoons, four labeled bowls, a timer and gloves
- Two colored garments to check (a new dark T-shirt, a red or navy item) and a white cotton cloth

Steps

1. **Hypothesis.** For each stain, predict the best of the four treatments and explain why with chemistry.
2. Put the same amount ($\frac{1}{2}$ tsp) of each stain on four swatches. Let all stains set for 2 hours. Rate each swatch 1 (heavy) before treatment.
3. Treat one swatch of each stain by each method: A cold water rinse and soak 15 min; B hot tap water rinse and soak 15 min; C cold rinse then plain detergent soak 30 min; D cold rinse then enzyme detergent soak 30 min. Use the same amounts and times.
4. Rinse all swatches in cool water, dry flat, and rate each from 1 (no change) to 5 (completely clean). Have a family member rate them blind too.
5. Treat any remaining tannin or dye stains with an oxygen-bleach soak (7.5 g/L, 1 hour) and rate again.
6. **Colorfastness.** Rub a damp white cloth firmly ten times over each colored garment (crocking). Then soak a hidden corner with a damp white cloth pressed against it for 10 minutes. Rate any color transfer.
7. **Conclude.** Make a table of best treatment by stain family. Did hot water help or hurt? Which garment should be washed separately?
8. **Repeat round.** Re-stain a protein swatch and dry it in a warm dryer before treating. How much harder is it to remove?

Tips

- Apply stains with a measuring spoon so each swatch gets the same amount.
- Blot, do not scrub: scrubbing spreads stains and roughens fibers.
- Keep the table on the laundry room wall afterward. It is the most used page of this course.

Check your work

- ☐ I stained and treated all swatches the same way, changing only the treatment.
- ☐ I rated results blindly with a second rater and calculated means.
- ☐ I produced a stain-treatment table explained by chemistry, and checked two garments for colorfastness.

LAB NOTEBOOK

1. Draw a surfactant molecule and a micelle around an oil droplet.
2. Make a care-symbol chart with every symbol you found and its meaning.
3. Tape in the treated swatches as a grid: stains down, treatments across, with ratings.

KEY FORMULAS

$$\text{mean rating} = \frac{\text{sum of ratings}}{\text{number of trials}}$$

mean rating = number of trials ÷ sum of ratings

$$\text{improvement} = \text{rating after treatment} - \text{rating before treatment}$$

improvement = rating after treatment – rating before treatment

From history. Before electric washing machines, laundry was often the hardest day of a household's week, and many families sent linen to washerwomen who worked at rivers and public washhouses. Electric washers spread through American homes from the 1920s to the 1950s, and with them came the detergents and care labels of this lesson.

WORKED EXAMPLES

Example 1. Egg-yolk stains rated 1 (heavy stain) before treatment. After cold rinse plus enzyme detergent, three swatches rated 5, 4 and 5; after hot rinse plus enzyme detergent, 2, 3 and 2. Find each mean and the improvements.

Show solution

1. Cold: $\frac{5 + 4 + 5}{3} = 4.67$ $35 + 4 + 5 = 4.67$; improvement $4.67 - 1 = 3.67$ $4.67 - 1 = 3.67$.

2. Hot: $\frac{2 + 3 + 2}{3} = 2.33$ $2 + 3 + 2 = 2.33$; improvement 1.33 1.33 .

Answer: Cold-first removed far more: hot water set the egg protein.

Example 2. A label lists 70% cotton, 25% polyester and 5% spandex for a 480 g pair of pants. How many grams of each? Which fiber limits the safe drying temperature?

Show solution

1. Cotton $480 \times 0.70 = 336$ g $480 \times 0.70 = 336$ g; polyester 120 g 120 g; spandex 24 g 24 g.

2. Spandex weakens with high heat, so it limits the dryer setting even though it is only 5%.

Answer: 336 g cotton, 120 g polyester, 24 g spandex; dry on low or medium to protect the spandex.

Example 3. Oxygen bleach is used at 1 scoop (30 g) per 4 L of soaking water. How much for a 10 L soak, and what is the concentration in g/L?

Show solution

1. Concentration: $30 \text{ g} \div 4 \text{ L} = 7.5 \text{ g/L}$ $30 \text{ g} \div 4 \text{ L} = 7.5 \text{ g/L}$.

2. For 10 L: $7.5 \times 10 = 75 \text{ g}$ $7.5 \times 10 = 75 \text{ g}$, 2½ scoops.

Answer: 75 g (2½ scoops) at 7.5 g/L.

PRACTICE

1. Easy In what year did the FTC first issue the Care Labeling Rule?

Show answer

1971.

2. Easy What does a triangle crossed out mean?

Show answer

Do not bleach.

3. Easy Why rinse a blood stain in cold water first?

Show answer

Hot water cooks the protein onto the fiber and sets the stain.

4. **Medium** Which enzyme digests protein stains, and which starch?

Show answer

Protease; amylase.

5. **Medium** Explain how a surfactant removes oil.

Show answer

Its oily tails dissolve into the oil and its water-loving heads face outward, forming micelles that water carries away.

6. **Medium** Draw or describe the symbol for “tumble dry, low heat.”

Show answer

A square with a circle inside and one dot.

7. **Medium** Why must chlorine bleach never be mixed with ammonia or vinegar?

Show answer

It releases dangerous gases (chloramines with ammonia, chlorine gas with acids).

8. **Hard** Give a step-by-step plan for removing chocolate from a cotton shirt.

Show answer

Scrape off excess; rinse from the back with cold water; treat with enzyme detergent (protein, starch); work in liquid detergent for the fat; launder warm; if a brown tannin mark remains, soak in oxygen bleach; air-dry until gone.

9. **Hard** A sweater label says 60% acrylic, 40% wool. Why would the care label likely say hand wash cold and dry flat?

Show answer

Wool felts with heat and agitation, and acrylic is heat-sensitive; cold hand washing and flat drying protect both.

10. **Hard** Stains were rated 2, 3, 3 and 4 before treatment and 5, 5, 4 and 5 after. Find the mean improvement.

Show answer

Before mean 3, after mean 4.75; improvement 1.75.

11. **Challenge** Isaiah 1:18 promises that scarlet sins shall be white as snow. Using this lesson's chemistry, explain why that picture would have struck an ancient hearer as nearly impossible, and why that matters to the promise.

Show answer

Scarlet and crimson were among the fastest dyes known, made to resist washing; no fuller could make dyed cloth white again. The promise describes a cleansing only God can do, beyond human power, which is the point of the comparison.

COMMON MISTAKES

- Using hot water on blood or egg. Cold first, always, for protein.
- Drying a stained garment. Heat sets most stains; check before the dryer.
- Mixing cleaning products. Never mix bleach with anything.

Make it a game · Symbol Snap. Make cards of 20 care symbols and 20 meanings. Deal them face down in a grid and play memory: turn two cards at a time, keeping any matched symbol-and-meaning pair. The player with the most pairs wins, but must read every pair aloud correctly to keep it.

Scripture. “Come now, and let us reason together, saith the LORD: though your sins be as scarlet, they shall be as white as snow; though they be red like crimson, they shall be as wool.” (Isaiah 1:18, KJV)

Every dyer and laundress knew scarlet would not wash out. The Lord's promise uses the hardest stain they knew to show a cleansing only He can give.

UNIT 6 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (7 pts)
Explain how an alum mordant fixes a natural dye, and why natural dyes take more readily on wool than on cotton.
2. (7 pts)
How much alum (15% WOF) and water (30:1) for 140 g of wool?
3. (7 pts)
Describe how indigo dyes cloth.
4. (7 pts)
Tell the story of Perkin's mauve in three or four sentences.
5. (7 pts)
Match each dye class to its fiber(s): acid, reactive, disperse, basic.
6. (7 pts)
How much dye for a 2.5% shade on 160 g of cotton? How much vinegar (5%) to make 1.5 L at 0.5%?
7. (7 pts)
Describe block, roller and screen printing and give one advantage of each.
8. (6 pts)
A fabric 44 in wide has $\frac{1}{2}$ in unprinted at each edge. How many $3\frac{1}{2}$ -in repeats fit, and what is the half-drop offset for a 5-in vertical repeat?
9. (7 pts)
Explain how Sanforizing and durable-press finishes work, and one trade-off of each.
10. (6 pts)
A 60.0 cm mark shrinks to 56.4 cm. Find the shrinkage and the cut length needed for 72 in finished.
11. (7 pts)
Describe the Triangle Shirtwaist fire briefly as fire-safety history: what happened, why so many died, and what changed.
12. (6 pts)
What do the Textile Fiber Products Identification Act (1958) and the FTC Care Labeling Rule (1971) require?
13. (6 pts)
Name the five care-symbol families and what an X means.
14. (6 pts)
Give the first treatment for blood, salad oil and tea stains, with the chemistry reason.
15. (7 pts)
Short essay (5–7 sentences): Natural dyes or synthetic dyes? Write a fair comparison using this unit's history and chemistry.

UNIT PROJECT: A DYED, PRINTED AND LABELED PIECE

Make one finished, useful textile that shows this unit's skills: for example, a tea towel or napkin set you dye (natural or synthetic, with a parent present) and block-print, or a dyed scarf with a printed border, to keep or give.

Sew in a care label you design that meets the FTC rules (fiber content by percent and correct care symbols) and attach a one-page record: dye recipe with WOF calculations, print plan with repeat measurements, heat-setting method, and the results of a five-wash

colorfastness and shrinkage test on a matching sample.

LOOK FOR	WHAT IT MEANS
Safety	Dyeing was done with a parent present in dye-only equipment; the record says so.
Color and print quality	Color is even, the print repeat is planned and regular, and both are fixed properly.
Accurate label	The care label states fiber content correctly and uses correct symbols for the fiber and finish.
Calculations and testing	WOF, repeat and shrinkage calculations are correct, and the fastness test is honestly reported.
Usefulness and finish	The piece is hemmed neatly and ready to use or give.

ANSWER KEY

1. Aluminum ions bind to the fiber and to dye molecules at once, forming an insoluble colored complex on the fiber. Wool's protein has many groups that bind metal ions and dyes; cellulose has fewer and usually needs tannin first.
2. 21 g alum; 4,200 g (4.2 L) water.
3. Insoluble indigo is reduced in an alkaline vat to a soluble yellow-green form that soaks into the fiber; in air it oxidizes back to insoluble blue, trapped in the fiber.
4. In 1856, eighteen-year-old William Perkin, a student of Hofmann, tried to make quinine from coal-tar aniline in his home lab. He got a black sludge that gave a purple solution which dyed silk fast. He patented it, built a factory at Greenford with his family, and mauve became the fashion, launching the synthetic dye industry.
5. Acid: wool, silk, nylon. Reactive: cotton, linen, rayon. Disperse: polyester, acetate. Basic: acrylic.
6. 4 g dye; $V_1 = 0.5 \times 1.5/5 = 0.15$ L $V_1 = 0.5 \times 1.5/5 = 0.15$ L (150 mL).
7. Block: hand-pressed carved blocks; flexible, small runs, hand quality. Roller: engraved copper cylinders print continuously; very fast. Screen: dye forced through stenciled mesh; large motifs, many colors, adaptable to rotary speed.
8. $[43/3.5] = 12$ $[43/3.5] = 12$; offset $2\frac{1}{2}$ in.
9. Sanforizing compresses cloth lengthwise when damp and hot, removing future shrinkage (small cost, does not stop felting). Durable press cross-links cellulose chains so cotton springs back from wrinkles (reduces strength and abrasion resistance).
10. 6%; $72/0.94 \approx 76.6$ in $72/0.94 \approx 76.6$ in.
11. On March 25, 1911, fire spread through a New York blouse factory full of cotton scraps; a locked exit, a collapsing fire escape and short ladders trapped workers, and 146 died. New York's investigating commission brought fire drills, sprinklers, unlocked exits and factory safety laws that shaped fire codes nationwide.
12. TFPIA: generic fiber names and percentages by weight, the maker or seller, and country of origin. Care rule: a permanent label giving at least one safe method of care.
13. Washtub (wash), triangle (bleach), square (dry), iron (iron), circle (professional cleaning); an X means do not.
14. Blood: cold rinse then enzyme (protease; heat sets protein). Oil: surfactant on the spot, warm wash (micelles). Tea: rinse then oxygen bleach (oxidizes tannin chromophores).
15. A strong essay credits natural dyes' beauty, history and gentle mordants (alum) and their costs (variability, fading, labor, scarce sources like murex), and synthetic dyes' range, fastness, consistency and affordability, along with their need for careful chemistry and safe handling; it concludes that each has a place and both deserve skill and care.

TOOLS, THE MACHINE AND THE SERGER

The second half of this course is construction, and it begins with the tools. The sewing machine is one of the great inventions of the nineteenth century: Walter Hunt's and Elias Howe's eye-pointed needles, Isaac Singer's practical machine of 1851 and the patent pool of 1856 put it in factories and then in homes across the world. You will learn exactly how a lockstitch forms (needle, hook, bobbin and take-up lever working in a fraction of a second), how needles, thread and tension must match the fabric, and how to clean, oil and care for a machine so it lasts for generations.

Then come seams. You will sew and test plain, French and flat-felled seams in the unit's seam-strength lab, meet Joseph Merrow's overlock and the modern serger, compare seam finishes in a wash test, and learn the physics of pressing (heat, moisture, pressure and cooling) that turns homemade sewing into professional work. Every tool is used only after a parent has watched you use it safely, and the machine is always unplugged before you change a needle, clean it or thread a serger.

PREREQUISITES

- A sewing machine in working order with its manual, and a parent to sign off each tool
- Units 4–5: thread, tex and tenacity; weaves and grain
- The bucket rig from earlier labs, a seam ripper, pins, an iron and a pressing surface

MASTERY CHECKLIST

- ☐ I can tell the history of Hunt, Howe, Singer and the Sewing Machine Combination accurately.
- ☐ I can name the parts of a sewing machine, thread it, wind and insert a bobbin, and change the needle safely.
- ☐ I can explain step by step how a lockstitch forms and diagnose tension problems from the stitch.
- ☐ I can choose needle size and type, thread and stitch length for a fabric, and convert stitch length to stitches per inch.
- ☐ I can sew plain, French and flat-felled seams, compare seam finishes, and measure seam strength and efficiency.
- ☐ I can press correctly, choosing heat, moisture, pressure and tools for each fiber.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Your machine's manual:** Free from the maker's website if you have lost it; search the model number. Lesson 7.1's maintenance follows it exactly.
- **A variety pack of machine needles:** Universal 70/10, 80/12 and 90/14, a ballpoint 80/12 and a denim 100/16 cover nearly everything in this course.
- **A tailor's ham and seam roll (or homemade substitutes):** A tightly rolled bath towel stands in for both; Lesson 7.5 shows a homemade clapper from a smooth hardwood block.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

7.1	Hunt, Howe and the Eye-Pointed Needle	3 sessions of 50–90 minutes
7.2	Singer, the Combination and the Lockstitch	3 sessions of 50–90 minutes
7.3	Seams and Seam Strength	3 sessions of 50–90 minutes
7.4	Merrow's Overlock and the Serger	3 sessions of 50–90 minutes
7.5	Pressing: Heat, Moisture and Pressure	3 sessions of 50–90 minutes

7.1 HUNT, HOWE AND THE EYE-POINTED NEEDLE

OBJECTIVES

- Tell the story of the sewing machine from Thimonnier and Hunt to Elias Howe's patent of 1846.
- Name the parts of a sewing machine and of a machine needle, and choose needle size and type for a fabric.
- Clean, oil and re-needle a machine safely, and convert stitch lengths and needle sizes.

Warm-up. Look at a hand-sewing needle and a sewing-machine needle side by side under your magnifier. Where is the eye on each? Why would a machine need the eye in a different place?

WATCH

Who Invented the Sewing Machine? | The Untold Story of Rivalry, Riots, and Reinvention

[History of Simple Things](#) · 9:45

<https://www.youtube.com/watch?v=llbv85waM-w>

WHEN TO WATCH

After “How they figured it out.” Keep a list of every inventor named and the one idea each contributed.

BACKUP VIDEO

HOW TO CLEAN AND OIL YOUR SEWING MACHINE

[MySewBliss](#) · 5:21

<https://www.youtube.com/watch?v=iIZul3Be1XI>

Before the studio lab. Watch one cleaning and oiling routine, then follow your own machine's manual, which may differ.

KEY TERMS

eye-pointed needle

A needle with the eye near the point, so the machine can push thread through the cloth without passing the whole needle through.

feed dogs and presser foot

The toothed bars under the needle that move fabric forward, and the foot that holds fabric against them.

ballpoint needle

A needle with a rounded tip that slips between knit loops instead of piercing and breaking them.

lockstitch

A stitch formed by two threads, a top thread and a bobbin thread, interlocking in the middle of the fabric layers (stitch type 301).

needle size

Given as metric/US, such as 80/12; the metric number is the blade's diameter in hundredths of a millimeter (80 = 0.80 mm).

scarf

The scooped-out notch on the back of a machine needle above the eye, where the hook catches the thread loop.

CORE IDEAS

The story. Many people tried to mechanize sewing. In 1830 the French tailor Barthélemy Thimonnier patented a chain-stitch machine and set up a workshop sewing army uniforms; tailors afraid for their livelihood broke into the shop and wrecked the machines. In New York around 1833–34 Walter Hunt built a machine with an eye-pointed needle and a shuttle that formed a lockstitch, but he never patented it, reportedly worrying it would put seamstresses out of work. (Hunt also invented the safety pin.) Then Elias Howe, a young Massachusetts machinist, built his own lockstitch machine with a curved, eye-pointed needle and a shuttle, and received a U.S. patent on September 10, 1846. In a public trial he outsewed five skilled seamstresses, yet he could not sell it.

How they figured it out. The problem was that a hand needle passes all the way through the cloth, eye last, and a machine cannot let go of its needle. The solution was to move the eye to the point and use two threads: the needle pushes a loop of top thread through the cloth, and something underneath (a shuttle in Howe's machine, a hook in later ones) passes a second thread through that loop. Pull both tight and they lock together. Howe's machine sewed only short straight seams, with the cloth hung on pins and advanced

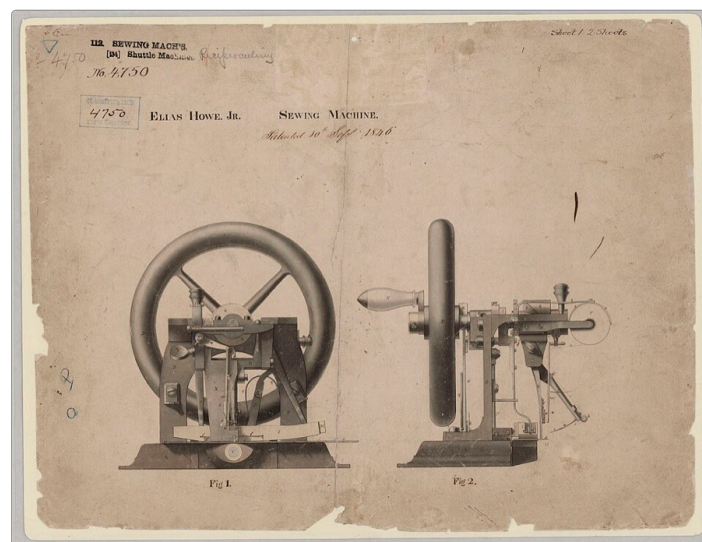
by hand. Inventors who followed added continuous feed, a presser foot and a vertical needle, and Howe spent years in court defending his patent, winning in 1854.

The fabric science. A machine needle has a flat-backed shank that fits the needle bar only one way, a shaft, a long groove on the front that shields the thread as it passes through the fabric, a scarf on the back where the hook picks up the loop, and the eye and point. Size and point must suit the fabric: fine needles (60/8–70/10) for lawn and silk, universal 80/12 for shirting, 90/14–100/16 for denim and canvas; ballpoint for knits so the needle parts the loops; sharp (microtex) for tightly woven fabrics. A dull or bent needle causes skipped stitches, pulled threads and a thumping sound, which is why sewers change needles often, at the start of each project or after several hours of sewing.

Care. Lint from thread and fabric packs into the bobbin area and feed dogs, and a dry machine wears its moving parts. Cleaning and oiling follow the manual exactly: some modern machines must never be oiled by the owner. The safety rule never changes: **unplug the machine** before cleaning, oiling, threading the bobbin area or changing the needle, and keep your foot off the pedal.

The studio lab. With your parent watching, you will learn your machine's parts and threading, then clean it, oil it if the manual says to, change the needle, and sew test lines on a woven and a knit with two different needles to see what the right needle does.

PICTURE STUDY



Elias Howe's Sewing Machine (patent drawing), Elias Howe Jr., for the U.S. Patent Office, 1846 · Ink drawing · U.S. National Archives
Image: [Wikimedia Commons](#), public domain

Patent drawings had to show an invention so clearly that a skilled mechanic could build it. Howe's drawing for his 1846 patent shows the curved needle with its eye near the point, the shuttle that carried the second thread, and the frame that held the cloth.

Look closely

- Find the needle. How is it shaped, and where does it enter the cloth?
- Find the shuttle. Which way would it travel through the loop?
- Find the cloth holder. How was the cloth moved along?
- Look for the crank or wheel that drove the machine. Where would the operator's hand go?

Talk about it

1. Howe's machine sewed only short straight seams. Which later inventions fixed that?
2. Why did patent drawings have to be so exact?
3. Compare this drawing with your own machine. What has stayed the same for nearly two centuries?

Safety first. This lesson begins the parent sign-off: a parent watches you thread, sew, clean and re-needle the machine before you use it alone, with a parent at home. Unplug the machine before opening any cover, cleaning, oiling or changing the needle. Keep fingers at least an inch from the needle, never sew over pins, tie back long hair, and drop used needles into a closed container, not the trash can loose.

STUDIO LAB

Know Your Machine: Anatomy, Care and the Right Needle

Question: Does the right needle really change stitch quality on wovens and knits? First you will learn, clean and service your machine; then you will test two needles on two fabrics.

You will need

- Your sewing machine, its manual, its cleaning brush and (only if the manual allows) sewing-machine oil
- New universal 80/12 and ballpoint 80/12 needles
- Scraps of quilting cotton and cotton jersey (from an old T-shirt), all-purpose polyester thread
- A small screwdriver if the manual requires it, a lint-free cloth and a closed container for used needles

Steps

1. **Hypothesis.** Predict what will happen when you sew jersey with a universal needle and with a ballpoint.
2. With the manual open, label a sketch of your machine: spool pin, thread guides, tension dial, take-up lever, needle, presser foot, feed dogs, bobbin winder, bobbin case, stitch length and width controls, handwheel, reverse lever.
3. Unplug the machine. Remove the needle, presser foot and needle plate as the manual shows. Brush out all lint from the feed dogs and bobbin area. Oil only where and if the manual directs, one drop each, then wipe away excess.
4. Insert a new universal needle, flat side of the shank to the back (on most machines), pushed all the way up, and tighten the screw.
5. Plug in, thread the machine and bobbin, and with your parent watching, sew three straight lines on the cotton and three on the jersey, slowly, hands flat on the fabric, fingers well away from the needle.
6. Unplug, change to the ballpoint needle, and sew three lines on each fabric again.
7. Stretch the jersey seams gently and examine all lines under the magnifier: skipped stitches, holes, puckers. Record each.
8. **Conclude.** Which needle served each fabric best, and why?
9. **Parent sign-off.** Ask your parent to initial a card listing each skill: thread, wind bobbin, insert bobbin, sew, change needle, clean. Tape it in your notebook.

Tips

- Take a phone photo of every step as you take the machine apart; the photos show you how it goes back together.
- Thread with the presser foot up, so the thread seats in the tension discs.
- Keep a maintenance log: date, needle size, hours sewn, cleaning. Machines cared for this way often last fifty years and more.

Check your work

- ☐ I cleaned and serviced my machine following its manual, unplugged throughout.
- ☐ I sewed and compared two needles on two fabrics and recorded the differences.
- ☐ My parent signed off each machine skill.

LAB NOTEBOOK

1. Paste your labeled machine sketch.
2. Draw a machine needle large and label shank, shaft, groove, scarf, eye and point.
3. Start a maintenance log page: date, task, needle, notes.

KEY FORMULAS

$$\text{stitches per inch (SPI)} = \frac{25.4 \text{ mm/in}}{\text{stitch length (mm)}}$$

$$\text{stitches per inch (SPI)} = \text{stitch length (mm)} \div 25.4 \text{ mm/in}$$

$$\text{needle blade diameter (mm)} = \frac{\text{metric size}}{100}$$

$$\text{needle blade diameter (mm)} = 100 \div \text{metric size}$$

From history. Howe was poor for years while others profited from sewing machines, but after winning his patent case he collected royalties on most machines sold in America until his patent expired in 1867. When the Civil War came, he is said to have equipped a regiment at his own expense and served in it as a private.

WORKED EXAMPLES

Example 1. Convert stitch lengths of 1.5, 2.5 and 4.0 mm to stitches per inch.

Show solution

$$1. 25.4/1.5 = 16.9, 25.4/2.5 = 10.2, 25.4/4.0 = 6.35$$

Answer: About 17, 10 and 6 SPI. 2.5 mm (about 10 SPI) is the usual straight stitch; 4 mm is a basting length.

Example 2. Find the blade diameter of 70/10 and 100/16 needles in millimeters and in thousandths of an inch.

Show solution

$$1. 70/10: 70/100 = 0.70 \text{ mm}; 0.70 \div 25.4 = 0.028 \text{ in}$$

$$2. 100/16: 1.00 \text{ mm} = 0.039 \text{ in}$$

Answer: 0.70 mm (0.028 in) and 1.00 mm (0.039 in). The bigger needle makes a hole 43% wider, which is why fine fabrics need fine needles.

Example 3. A home machine sews at 800 stitches per minute with a 2.5 mm stitch. How many inches of seam does it sew per minute at full speed, and how long would a skilled hand sewer at 30 stitches per minute (5 mm stitch) take to sew the same length?

Show solution

$$1. \text{ Machine: } 800 \times 2.5 \text{ mm} = 2,000 \text{ mm} = 78.7 \text{ in}$$

$$2. \text{ Hand: } 30 \times 5 \text{ mm} = 150 \text{ mm/min}; \text{ time } 2,000 \div 150 \approx 13.3 \text{ min}$$

Answer: About 79 in a minute by machine against about 13 minutes by hand: why Howe could outsew five seamstresses.

PRACTICE

1. **Easy** When did Elias Howe receive his sewing-machine patent?

Show answer

September 10, 1846.

2. **Easy** Why did Walter Hunt reportedly not patent his machine?

Show answer

He worried it would put seamstresses out of work.

3. **Easy** What must you always do before changing a needle or cleaning the bobbin area?

Show answer

Unplug the machine (and keep your foot off the pedal).

4. Medium Convert 3.0 mm to SPI.

Show answer

About 8.5 SPI.

5. Medium What stitch length in mm gives 12 SPI?

Show answer

$25.4/12 \approx 2.1$ mm

6. Medium Which needle would you choose for a cotton jersey T-shirt and for denim? Why?

Show answer

Ballpoint 80/12 for jersey (parts the loops); jeans/denim 100/16 for denim (strong, sharp, heavy fabric).

7. Medium What does the long groove on the front of a machine needle do?

Show answer

It shelters the thread as the needle passes through the fabric so the thread is not abraded or pushed aside.

8. Hard A seam is 42 in long sewn at 2.2 mm. How many stitches is that?

Show answer

$42 \times 25.4/2.2 \approx 485$

9. Hard List three symptoms of a dull or wrong needle.

Show answer

Skipped stitches, pulled or snagged threads (or holes in knits), a popping or thumping sound, puckering.

10. Hard Why did Howe's needle need its eye at the point, while a hand needle has its eye at the other end?

Show answer

A machine holds its needle and cannot pass it through the cloth; the eye at the point lets it push a loop of thread through and withdraw, with a second thread locking the loop below.

11. Challenge Thimonnier's machines were wrecked and Hunt held back his invention to protect seamstresses. Weigh these responses against the long-term effects of the sewing machine on workers and families.

Show answer

A fair answer notes real short-term fear and job loss, then the long-term effects: cheaper clothing, new factory and home-sewing work, and machines that eased household labor; it may suggest that helping workers adapt serves better than suppressing invention.

COMMON MISTAKES

- Threading with the presser foot down. The tension discs stay closed and the thread is not tensioned, so loops form underneath.
- Inserting the needle backward or not fully up. It skips stitches or strikes the plate.
- Oiling a machine that the manual says not to. Read first.

Make it a game · Thread Race. With the machine unplugged and a parent timing, each player threads the machine from spool to needle and inserts the bobbin. Fastest correct threading wins, but a parent checks every guide: a missed guide adds ten seconds. Second round: blindfolded naming of machine parts by touch.

7.2 SINGER, THE COMBINATION AND THE LOCKSTITCH

OBJECTIVES

- Tell the story of Isaac Singer's machine (1851), the Sewing Machine Combination (1856) and the installment plan that brought machines into homes.
- Explain step by step how a lockstitch forms and how top and bobbin tension must balance.
- Diagnose tension problems from test stitching and calculate thread consumption.

Warm-up. Sew a short line with one color of thread on top and a contrasting color in the bobbin. Look at both sides with the magnifier. Can you see the other color peeking through on either side? Where do the two threads meet?

WATCH

Why Bobbins? How a Lock Stitch is Formed in a Sewing Machine

Alexander Dyer · 7:03

<https://www.youtube.com/watch?v=Og1hM8iS22Q>

WHEN TO WATCH

After “The fabric science.” Watch the loop form and the hook catch it; pause and describe each step before the narrator does.

BACKUP VIDEO

Stitch Type 301: Double Lockstitch in Slow Motion

Groz-Beckert · 2:35

<https://www.youtube.com/watch?v=zK9h8ByMcvG>

A slow-motion close-up of the lockstitch forming in a real machine.

KEY TERMS

rotary hook

The spinning hook beneath the needle plate that catches the needle-thread loop and carries it around the bobbin case; Allen B. Wilson patented an early one in 1851.

take-up lever

The arm that rises after each stitch to pull the loop up and tighten the stitch.

thread tension

The resistance applied to the top thread by the tension discs and to the bobbin thread by the bobbin case's spring.

balanced tension

Tension at which the two threads lock in the middle of the fabric, so neither shows on the other side.

patent pool

An agreement among patent holders to share their patents and divide the royalties, as in the Sewing Machine Combination of 1856.

installment plan

Buying an item with a down payment and regular payments over time; Singer's company used it to sell machines to families.

CORE IDEAS

The story. In 1850 Isaac Merritt Singer, a machinist and former traveling actor, was asked to look at a balky sewing machine in a Boston shop. He sketched a better design that night and, by his own account, built it in eleven days: a needle moving straight up and down, a presser foot to hold the cloth, a table to rest it on, and continuous feed. He patented it on August 12, 1851. It worked, and it sold. But Howe, Singer, Wheeler & Wilson, Grover & Baker and others were soon suing one another so constantly (the “sewing machine war”) that no one could profit. In 1856 they agreed to pool their patents in the Sewing Machine Combination, pooling licenses and paying Howe a royalty on each machine, until the last key patents expired in 1877.

How they figured it out. Building a good machine was only half the problem; a family could hardly afford one. Singer's partner, the lawyer Edward Clark, offered machines on an installment plan, a small payment down and the rest over months, along with sewing lessons and agents in every town. Singer's company became one of the first great international businesses, with factories in America

and Scotland, and the sewing machine became perhaps the first expensive machine many ordinary homes ever owned. Women who sewed for their families or for pay could now make a shirt in an hour instead of a day.

The fabric science. A lockstitch forms in five quick steps. (1) The needle descends, carrying the top thread through the fabric. (2) As it begins to rise, friction holds the thread on the scarf side, so it bulges into a small loop. (3) The point of the rotating hook catches that loop and carries it around the bobbin case, so the bobbin thread passes through it. (4) The take-up lever rises and pulls the loop up, drawing the interlock into the fabric. (5) The feed dogs move the fabric one stitch length, and the cycle repeats, hundreds of times a minute. The two threads should lock in the middle of the layers: if the top tension is too tight, bobbin thread is pulled up to the top; too loose, top thread loops show underneath.

Thread consumption. Because each thread travels along the seam and also in and out through the fabric, a lockstitch uses much more thread than the seam is long. A simple model: in each stitch of length s through fabric of total thickness t , each thread travels about $s + t$, so both threads together use about $2(s + t)$ per stitch. Short stitches in thick fabric use the most thread.

The studio lab. You will sew a tension ladder: rows of stitching at different top-tension settings with contrasting top and bobbin threads, then examine where the lock sits in each row, find your machine's balanced setting for two fabrics, and check the thread-consumption model by unpicking and measuring.

PICTURE STUDY



Singer Sewing Machine Patent Model, No. 8,294, Isaac M. Singer, 1851 · Patent model (metal and wood), photographed · Smithsonian Institution
Image: [Wikimedia Commons](#), public domain

Until 1880 American inventors often had to send the Patent Office a working model. This is the model for Singer's patent of August 12, 1851. Its arrangement of overhanging arm, vertical needle and presser foot over a flat table is still the shape of nearly every sewing machine.

Look closely

- Find the needle bar. Does it move straight up and down or swing in an arc?
- Find the presser foot. What job does it do?
- Find the spool of thread. How does the thread reach the needle?
- Look under the table. What might be hidden there?

Talk about it

1. Compare this model with your own machine. Which parts are recognizably the same?
2. Why would a vertical needle and a flat table make sewing easier than Howe's design?
3. A model like this had to work. What does that suggest about Singer's skill as a mechanic?

Safety first. Unplug before rethreading the bobbin area or adjusting the bobbin case. Change the top tension only with the presser foot down and the machine stopped. Keep fingers an inch from the needle and pull each pin before it reaches the presser foot.

The Tension Ladder

Question: At what top-tension setting does your machine lock its stitches in the middle of the fabric, and does that setting change with fabric thickness? You will sew a tension ladder and check the thread-consumption model.

You will need

- Two contrasting all-purpose threads (dark on top, light in the bobbin)
- Two fabrics: a lightweight shirting (2 layers) and a denim or canvas (2 layers), about 8 × 12 in each
- A seam ripper, a ruler in mm, the 10× magnifier and a marking pencil

Steps

1. **Hypothesis.** Predict your machine's balanced top-tension number for each fabric.
2. Thread dark thread on top (foot up) and light thread in the bobbin. Set stitch length to 2.5 mm.
3. On the shirting, sew a 6-in row at each top-tension setting from the lowest to the highest, 1 in apart. Write the setting beside each row in pencil.
4. Repeat on the denim with a denim needle.
5. Examine each row on both sides under the magnifier. Mark rows where light shows on top (top too tight) or dark loops show underneath (top too loose). Circle the balanced row for each fabric.
6. **Thread check.** On a balanced 10-cm length of shirting seam, unpick carefully and measure the length of top and bobbin thread pulled out. Compare with the $2(s + t)$ model, measuring fabric thickness by folding and measuring a stack.
7. **Conclude.** Was the balanced setting the same for both fabrics? How well did the model predict the thread used?
8. **Repeat round.** Change stitch length to 1.5 mm and 4 mm on the shirting at the balanced tension. Do they still balance?

Tips

- Most machines balance near the middle of the dial; if yours does not, check threading and lint before turning the dial far.
- Do not adjust the bobbin case screw unless the manual says to; small turns make big changes.
- Record the balanced settings on a card taped inside your machine cover.

Check your work

- ☐ I sewed a full tension ladder on two fabrics and identified the balanced setting for each.
- ☐ I diagnosed unbalanced rows correctly from both sides.
- ☐ I tested the thread-consumption model against a measured seam.

LAB NOTEBOOK

1. Draw the five steps of lockstitch formation as a comic strip.
2. Draw cross-sections of a balanced, a too-tight and a too-loose lockstitch.
3. Tape in your tension ladders with the balanced rows circled.

KEY FORMULAS

$$\text{thread per stitch} \approx 2(s + t)$$

$$\text{thread per stitch} \approx 2(s + t)$$

$$\text{thread-to-seam ratio} \approx \frac{2(s + t)}{s}$$

$$\text{thread-to-seam ratio} \approx s2(s + t)$$

From history. Singer's company opened a factory at Clydebank, Scotland, in 1884, which became one of the largest factories in Europe. By the early 1900s Singer machines were sold on every inhabited continent, and many families still sew on treadle machines more than a century old.

WORKED EXAMPLES

Example 1. A seam in two layers of shirting (total thickness 0.6 mm) uses a 2.5 mm stitch. Estimate the thread-to-seam ratio and the thread used in a 1 m seam.

Show solution

$$1. \frac{2(2.5 + 0.6)}{2.5} = \frac{6.2}{2.5} = 2.482.52(2.5 + 0.6) = 2.56.2 = 2.48.$$

$$2. 1 \text{ m} \times 2.48 \approx 2.5 \text{ m} \quad 1 \text{ m} \times 2.48 \approx 2.5 \text{ m, about 1.24 m each of top and bobbin thread.}$$

Answer: About 2.5 m of thread per meter of seam.

Example 2. Denim seams sew through four layers totaling 3.2 mm with a 3.0 mm stitch. Find the ratio, and how many meters of thread a pair of jeans with 9 m of seams needs.

Show solution

$$1. \frac{2(3.0 + 3.2)}{3.0} = \frac{12.4}{3.0} = 4.133.02(3.0 + 3.2) = 3.012.4 = 4.13.$$

$$2. 9 \times 4.13 \approx 37 \text{ m} \quad 9 \times 4.13 \approx 37 \text{ m.}$$

Answer: About 4 times the seam length, roughly 37 m of thread on this model, before topstitching.

Example 3. Diagnosis. On a test seam with red top thread and white bobbin thread, small red loops show on the underside, and the top looks flat with white dots. What is wrong and what do you change?

Show solution

1. Red top thread is being pulled to the underside, so the top thread is too loose relative to the bobbin (or the machine is threaded wrong).
2. First rethread the top with the presser foot up, making sure the thread is between the tension discs.
3. If the problem remains, raise the top tension a number at a time and test again.

Answer: Top tension too loose (often from threading with the foot down). Rethread, then increase top tension gradually.

PRACTICE

1. **Easy** When did Singer patent his machine, and name two of its improvements.

Show answer

August 12, 1851; a vertical straight needle, a presser foot (also a table and continuous feed).

2. **Easy** What was the Sewing Machine Combination of 1856?

Show answer

A patent pool in which the leading makers shared their patents and royalties, ending the lawsuits.

3. **Easy** Where should the two threads of a lockstitch lock?

Show answer

In the middle of the fabric layers.

4. **Medium** Estimate the thread-to-seam ratio for a 2.0 mm stitch through 1.0 mm of fabric.

Show answer

$$2(3.0)/2.0 = 3.02(3.0)/2.0 = 3.0$$

5. **Medium** List the five steps of lockstitch formation in order.

Show answer

Needle descends; loop forms as it rises; hook catches loop and carries it around the bobbin; take-up lever tightens the stitch; feed dogs advance the fabric.

6. **Medium** Bobbin thread shows as dots on the top of the seam. Which tension is too tight?

Show answer

The top tension (it pulls the bobbin thread up).

7. **Medium** How did the installment plan change who owned sewing machines?

Show answer

Families who could not pay the full price at once could buy a machine with small regular payments, so machines spread into ordinary homes.

8. **Hard** A 100 m bobbin holds thread for how many meters of seam at a ratio of 2.5, if half the thread used is bobbin thread?

Show answer

Bobbin thread per meter of seam is 1.25 m; $100/1.25 = 80$ m $100/1.25 = 80$ m of seam.

9. **Hard** Why does a shorter stitch length use more thread per centimeter of seam, according to the model?

Show answer

Each stitch adds the fabric thickness t twice-over in the $2(s + t)$ term; more stitches per centimeter means more thickness crossings, so the ratio $2(s + t)/s$ rises as s falls.

10. **Hard** Name two causes of tension problems that have nothing to do with the tension dial.

Show answer

Threading with the presser foot down, lint in the tension discs or bobbin case, wrong bobbin, bobbin inserted backward, wrong needle, poor thread.

11. **Challenge** The patent pool ended a costly legal war but kept prices high until 1877. Weigh the benefits and costs of the Combination for inventors and for families.

Show answer

Benefits: ended wasteful lawsuits, let makers improve and sell machines, rewarded inventors. Costs: royalties kept prices high and limited competition until patents expired, after which prices fell and machines spread further.

COMMON MISTAKES

- Turning the tension dial first. Rethread (foot up), clean lint and change the needle before touching tension.
- Using different threads on top and in the bobbin for real sewing. Match weights so tension balances.
- Thinking the bobbin thread is “the bottom stitch.” Both threads form every stitch together.

Make it a game • Tension Detective. A parent secretly sets the top tension (very loose, normal or very tight) and sews a short seam with contrasting threads. Players examine both sides and call the setting. Three correct calls in a row earn the title of tension detective; a wrong call means you reset the machine to balance.

7.3 SEAMS AND SEAM STRENGTH

OBJECTIVES

- Sew plain, French and flat-felled seams with accurate seam allowances, and name common stitch types.
- Explain what makes a seam strong (stitch length, thread, seam type) and how a seam can fail.
- Run the unit's seam-strength lab and calculate seam efficiency.

Warm-up. Turn a pair of jeans and a dress shirt inside out. Find three different seams. Which seams hide their raw edges completely? Which look strongest? Which would you most expect to fail first, and where?

WATCH

Flat Felled Seams vs. French Seams The Difference and How to Sew

[Sew Sew Live](#) · 8:34

<https://www.youtube.com/watch?v=5h5aohgMt70>

WHEN TO WATCH

Watch once through, then again at the machine with your fabric strips, pausing after each fold and press.

BACKUP VIDEO

How to Sew a Flat Felled Seam aka The Strongest Seam

[MadamSew](#) · 2:11

<https://www.youtube.com/watch?v=tulhKc4-OnA>

A quick review of the flat-felled seam, the seam of work shirts and jeans.

KEY TERMS

seam allowance

The distance from the cut edge to the stitching line. Commercial home patterns usually use $\frac{5}{8}$ in (1.5 cm); quilting uses $\frac{1}{4}$ in.

French seam

A seam sewn twice, first wrong sides together, then right sides together, enclosing the raw edges; ideal for sheer and fraying fabrics.

seam efficiency

The strength of a seam as a percent of the strength of the unseamed fabric.

plain seam

Two layers sewn right sides together along the seam line, then pressed open or to one side.

flat-felled seam

A strong, flat seam in which one allowance is trimmed and the other folded over it and stitched down, enclosing both edges; used on jeans and work shirts.

seam slippage

Yarns pulling away from a seam line in loosely woven fabric, leaving a gap, even though the thread has not broken.

CORE IDEAS

The story. The apostle Paul worked with Aquila and Priscilla as a tentmaker (Acts 18:3), sewing heavy panels of goat-hair cloth or leather into shelters that had to stand up to wind and rain. A tent is only as strong as its seams. So is a sail, a parachute or a pair of work pants. In 1917–1918, Red Cross volunteers across America gathered in sewing rooms to sew hospital garments, bandages and clothing for families uprooted by the war by the hundreds of thousands, and their instructions insisted on seams that would survive hard use and boiling.

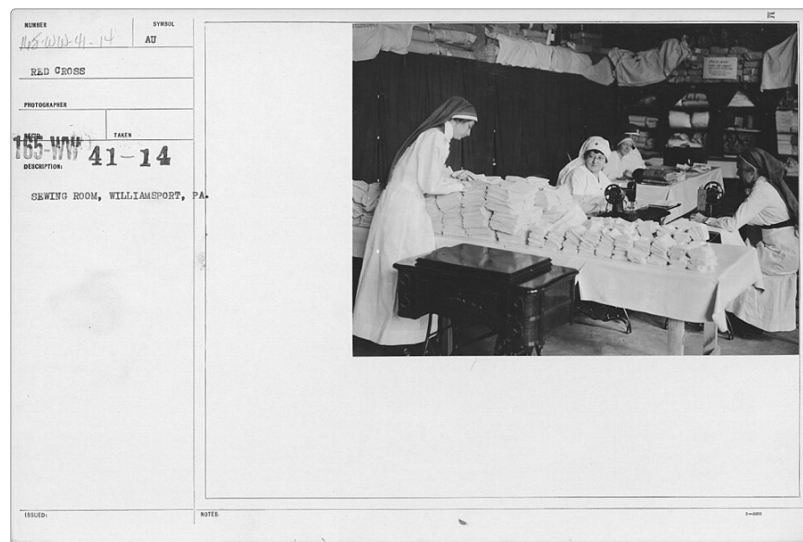
How they figured it out. Tailors and sailmakers learned by long experience that the strongest seams enclose their edges and spread the load over several rows of stitches. The flat-felled seam, folding one allowance over the other and stitching twice, became the seam of work clothes because it is strong, flat and has no raw edges to fray. The French seam, invented for fine linens and sheer fabrics, gives a neat enclosed seam without extra stitching on the outside. Industry later numbered stitch types by their structure in standards: 301 is the lockstitch, 401 the two-thread chainstitch, the 500s the overlock stitches.

The fabric science. A seam can fail in three ways: the thread breaks, the fabric tears beside the stitches, or the yarns slip out of the seam (slippage). Shorter stitches put more thread across each inch, raising strength, until the needle holes are so close that they weaken the fabric like a perforated stamp sheet. A good seam is designed so the seam is nearly as strong as the fabric (high seam efficiency) but, ideally, the thread breaks before the fabric tears, because a broken seam is easy to re sew and a torn garment is not. Seam allowance matters too: too narrow an allowance in a loose weave invites slippage.

Accuracy. Most seam problems are measuring problems. A 1/8-in error on each of the four side seams of a garment adds up to a full inch of fit. Use the throat plate's seam guide or a strip of tape, sew at an even speed, and press every seam before crossing it with another.

The studio lab. This is the unit's seam-strength lab. You will join identical fabric strips with plain seams at three stitch lengths, a French seam and a flat-felled seam, load each to failure with the bucket rig, record how it failed, and compare with unseamed strips to find seam efficiency.

PICTURE STUDY



American Red Cross Sewing Room, Williamsport, Pennsylvania, Photographer for the American Red Cross, c. 1917–18 · Photograph · U.S. National Archives

Image: [Wikimedia Commons](#), public domain

During World War I, volunteers in thousands of American towns gathered in Red Cross workrooms to sew hospital garments, bandages, and clothing for soldiers and for families driven from their homes. Their work was inspected, and pieces with poor seams were sent back.

Look closely

- Count the sewing machines. Are they treadle or electric?
- Find someone cutting, someone sewing and someone finishing by hand. How is the work divided?
- Look for stacks of finished pieces. What might they be?
- Notice the light and the arrangement of the tables. How was this room organized for work?

Talk about it

1. Why would the Red Cross insist on strong, enclosed seams for hospital garments that would be boiled?
2. What would a quality inspector look for on every seam?
3. What does this room tell you about sewing as service to others?

Safety first. Pins come out before they reach the presser foot; never sew over them. Keep fingers an inch from the needle and guide fabric with flat hands. Press each seam with the iron set for the fiber, the iron resting upright between uses, and keep the cord where no one can trip on it.

The Seam-Strength Lab

Question: How strong are plain seams at different stitch lengths, French seams and flat-felled seams, compared with the fabric itself? You will sew identical seamed strips, break them, and calculate seam efficiency.

You will need

- ½ yd of medium-weight cotton (quilting cotton or light twill), prewashed
- All-purpose polyester thread, a universal 80/12 needle, the bucket rig, binder clips and the scale
- A rotary cutter, mat and ruler, pins and the iron

SEAMED TEST STRIPS

Finished size: Six sets of three strips, each 1 × 12 in with the seam across the middle · About 2 hours

Fabric and notions

- Rectangles 4 × 7 in of the same cotton, all cut on the lengthwise grain, two per seamed sample
- Thread to match in the top and bobbin

How to make it

1. Cut 20 rectangles 4 × 7 in on the lengthwise grain, all from the same fabric.
2. Plain seams: join pairs along a 4-in edge right sides together with a ⅝-in allowance, at stitch lengths 1.5, 2.5 and 4.0 mm (one pair each). Press seams open.
3. French seam: sew a pair wrong sides together at ¼ in, trim to ⅛ in, press, fold right sides together and sew again at ⅜ in. Press to one side.
4. Flat-felled seam: sew a pair right sides together at ⅝ in, trim one allowance to ¼ in, fold the wider one over it, press, and edgestitch it flat.
5. Leave two rectangles unseamed as controls.
6. Cut each seamed panel into three strips 1 in wide (plus a little extra to fray down to exactly 1 in), with the seam crossing the middle of each strip.

Fabric check: A firm, medium-weight cotton gives clear results; prewash it so shrinkage does not distort the strips. Avoid stretchy or loosely woven fabrics for a first test; save a loose weave for the slippage repeat round.

Steps

1. **Hypothesis.** Rank the five seam types by strength and predict the efficiency of the strongest.
2. Make the strips following the pattern card. Label each with its seam type.
3. Break three unseamed control strips with the bucket rig (clips 2 in from each end). Record the mean.
4. Break all seamed strips the same way. For each, record the load and how it failed: thread broke, fabric tore beside the seam, fabric tore elsewhere, or slippage.
5. Calculate the mean breaking load and seam efficiency of each seam type.
6. **Conclude.** Which seam was strongest? Did stitch length behave as the lesson predicted? Which failure mode would you want in a real garment?
7. **Repeat round.** Repeat the 2.5-mm plain seam in a loosely woven fabric (cheesecloth, gauze or a loose linen) with ¼-in and ⅝-in allowances. Do you see slippage?

Tips

- Strong cotton strips may hold more than your bucket. Fray them narrower (½ in) for all tests, including the controls.
- Sew every seam at the same speed with the same thread from the same spool.
- Keep the failed strips in order on a page; the failure modes tell as much as the numbers.

Check your work

- ☐ I cut every strip on the same grain and width, changing only the seam.

- ☐ I tested controls and calculated seam efficiencies correctly.
- ☐ I recorded and explained each failure mode.

LAB NOTEBOOK

1. Draw cross-sections of a plain seam pressed open, a French seam and a flat-felled seam, labeling every layer and fold.
2. Make a bar chart of breaking load by seam type with the control as a line across it.
3. Tape in one failed strip of each type with its failure mode.

KEY FORMULAS

$$\text{seam efficiency} = \frac{\text{seam breaking load}}{\text{fabric breaking load}} \times 100\%$$

$$\text{seam efficiency} = \frac{\text{seam breaking load}}{\text{fabric breaking load}} \times 100\%$$

$$\text{fit change} = \text{error per seam allowance} \times \text{number of seam allowances affected}$$

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From history. The American Red Cross enrolled millions of volunteers in World War I, and its workrooms produced hundreds of millions of surgical dressings and many millions of garments, including the hospital shirts, pajamas and clothing for war-stricken families that came from rooms like the one in this lesson's picture.

WORKED EXAMPLES

Example 1. Unseamed 1-in strips of a cotton twill break at a mean of 18.0 kg. Plain seams at 2.5 mm break at 13.5 kg; flat-felled seams at 16.6 kg. Find each seam efficiency.

Show solution

$$1. \text{ Plain: } \frac{13.5}{18.0} \times 100\% = 75\%$$

$$2. \text{ Flat-felled: } \frac{16.6}{18.0} \times 100\% = 92\%$$

Answer: 75% and 92%; the flat-felled seam nearly matches the fabric.

Example 2. A skirt has front and back pieces joined by two side seams. If every seam is sewn $\frac{1}{8}$ in too wide, how much smaller is the skirt's circumference?

Show solution

1. Each side seam joins two allowances, so each loses $\frac{1}{8}$ in from each piece: $2 \times \frac{1}{8} = \frac{1}{4}$ in per seam.

2. Two seams: $2 \times \frac{1}{4} \text{ in} = \frac{1}{2} \text{ in}$ $2 \times 41 \text{ in} = 82 \text{ in}$

Answer: Half an inch smaller. In a garment with four seams around the body, a full inch.

Example 3. Seams at 1.5, 2.5 and 4.0 mm stitch length broke at 12.8, 13.5 and 10.2 kg. Which length is strongest, and why might the shortest not win?

Show solution

1. Strongest: 2.5 mm at 13.5 kg.

2. At 1.5 mm, the needle holes are close enough to weaken the fabric along the seam line, so the fabric tore beside the stitches before the extra thread could help.

Answer: 2.5 mm; very short stitches perforate and weaken the fabric.

PRACTICE

1. **Easy** What is the standard seam allowance on commercial home sewing patterns?

Show answer

$\frac{5}{8}$ in (1.5 cm).

2. **Easy** Which seam encloses raw edges for sheer fabric with no stitching visible outside?

Show answer

The French seam.

3. **Easy** What were Paul, Aquila and Priscilla by trade?

Show answer

Tentmakers (Acts 18:3).

4. **Medium** Fabric breaks at 20 kg and a seam at 15 kg. Find the seam efficiency.

Show answer

75%.

5. **Medium** Name three ways a seam can fail.

Show answer

Thread breaks, fabric tears beside the seam, or yarns slip out of the seam (slippage).

6. **Medium** Why is it usually better for the thread to break before the fabric?

Show answer

A broken seam can be resewn; torn fabric usually cannot be mended invisibly.

7. **Medium** Describe the two steps of a French seam.

Show answer

Sew wrong sides together with a narrow seam, trim and press; fold right sides together enclosing the edges and sew again.

8. **Hard** A shirt has two side seams and two sleeve seams. If each seam is sewn 3 mm too narrow, how much larger is the chest circumference?

Show answer

Side seams only affect the chest: $2 \text{ seams} \times 2 \text{ allowances} \times 3 \text{ mm} = 12 \text{ mm}$ larger.

9. **Hard** Why does a loosely woven fabric need a wider seam allowance or a finished seam?

Show answer

Loose yarns slip out of a narrow allowance under stress (slippage) and fray; more fabric or an enclosed seam holds them.

10. **Hard** A seam efficiency of 105% is measured. What does that suggest happened?

Show answer

The strip broke away from the seam, in the fabric, at a slightly higher load than the average unseamed strip: within measurement scatter, the seam is as strong as the fabric.

11. **Challenge** Design the seams for a heavy canvas tent bag that will carry 25 lb by its handles. Name seam types, stitch length, thread and reinforcement, with reasons.

Show answer

For example: flat-felled or double-stitched seams, 3–3.5 mm stitches, heavy-duty polyester thread, and box-X reinforcement where handles attach, spreading the load over many stitches.

COMMON MISTAKES

- Sewing a French seam right sides together first. Start wrong sides together, or the raw edges end up outside.
- Not pressing between steps. Every seam is pressed before it is crossed or folded.
- Guessing the seam allowance. Use the plate guide or tape every time.

Make it a game · Seam Spotter. Set a timer for five minutes and hunt the house for seams: on jeans, shirts, towels, bags, curtains, a tent or backpack. Score one point per seam type found (plain, French, flat-felled, overlocked, bound, topstitched) and a bonus for the oldest garment whose seams are still perfect.

Scripture. “And because he was of the same craft, he abode with them, and wrought: for by their occupation they were tentmakers.” (Acts 18:3, KJV)

Paul supported his ministry with his hands, stitching tents with Aquila and Priscilla. Strong seams were his trade, and honest work was part of his witness.

7.4 MERROW'S OVERLOCK AND THE SERGER

OBJECTIVES

- Describe the history of the overlock stitch from the Merrow Machine Company to the home serger.
- Explain how a serger's needles, loopers, knife and differential feed form an overlock seam, and serger safety.
- Compare seam finishes (pinked, zigzag, turned-and-stitched, bound, serged) in a wash test and calculate fray loss.

Warm-up. Look inside a store-bought T-shirt and a pair of pajama pants. Find seams whose edges are wrapped in a web of thread. Count the threads you can see. How is it different from the stitching on top?

WATCH

Beginner's Guide to Serging (Ep 1): Understanding Your Serger

[Sewing Parts Online](#) · 3:42

<https://www.youtube.com/watch?v=crrKtd98j68>

WHEN TO WATCH

Watch to learn the serger's parts (two needles, two loopers, knife, differential feed) and safety rules before the seam-finish lab, with the manual open if you have a serger.

BACKUP VIDEO

Threading a 4 Thread Serger Overlock Stitch - SINGER® 14CG754

[Singer Sewing Company](#) · 14:20

<https://www.youtube.com/watch?v=BhEtdNnNtos>

Watch a 4-thread serger threaded step by step by the maker's own teacher.

KEY TERMS

overlock stitch

A stitch that sews a seam and wraps its raw edge in thread at the same time, made by one or two needles and one or two loopers.

looper

A curved, needle-less arm in a serger that carries thread around the edge of the fabric to form the overcast.

differential feed

Two sets of feed dogs moving at different speeds, to prevent stretching knits or to gather fabric.

serger

The home name for an overlock machine: it trims, sews and overcasts an edge in one pass.

knife

The blade in a serger that trims the seam allowance just before the stitch forms.

seam finish

Any treatment that keeps a raw seam allowance from fraying: pinking, zigzag, turned-and-stitched, binding, serging or an enclosed seam.

CORE IDEAS

The story. In the 1870s and 1880s the Merrow family of Connecticut, who ran a knitting mill, built machines to finish the cut edges of knitted goods so they would not unravel: first a crochet machine, then, in the late 1880s, the overlock or overseaming machine, which stitched and covered an edge in one pass. The Merrow Machine Company's overedge stitches went on to finish blankets, hosiery and garments around the world. For most of the twentieth century overlockers were factory machines; small home sergers reached sewing rooms in the 1960s and 1970s, and today nearly every ready-made knit garment has serged seams.

How they figured it out. An overlock stitch uses no bobbin. One or two needles sew through the fabric as in a chainstitch, while one or two loopers, curved arms without eyes at their points, swing across above and below the edge, carrying threads that interlock with the needle thread and with each other around the cut edge. A knife trims the allowance just before the stitch forms, so the edge is neat and even. A 3-thread overlock finishes an edge or sews a light seam; a 4-thread overlock adds a second needle line, a safety stitch, for stronger seams in knits.

The fabric science. Fraying happens because cut yarns at a woven edge are held only by the interlacing; washing and wear shake them loose one by one. A seam finish works in one of three ways: by cutting a zigzag edge so loosened yarns are short (pinking), by stitching over the edge so yarns cannot escape (zigzag, serging), or by folding or binding the edge away entirely (turned-and-stitched, Hong Kong binding, French and flat-felled seams). Knits do not fray, but they can run and curl; serging with differential feed keeps their edges flat without stretching them out of shape.

Serger safety. A serger has a real knife and moves fast. Unplug it before threading, opening covers or changing needles; keep fingers away from the front of the presser foot where the knife cuts; never serge over pins, which ruin the knife and can throw pieces; and lower the knife or work slowly near curves. You may use a serger alone only after a parent has watched you use it safely. A serger is never required in this course; a zigzag stitch and the seams of Lesson 7.3 finish anything.

The studio lab. You will finish identical seam allowances six ways, wash them five times, and measure how much each frays, then decide which finish to use on your Unit 9 garment.

PICTURE STUDY



A Raveler and a Looper, Loudon Hosiery Mills, Lewis W. Hine, 1910 · Photograph · Library of Congress, National Child Labor Committee collection

Image: [Wikimedia Commons](#), public domain

Before overlockers were everywhere, knit stockings were closed at the toe on looping machines: a worker hung each loop of the knit edge on a ring of fine points so the machine could chain them shut, loop by loop. In hosiery mills this exacting work was often given to children, as Lewis Hine recorded for the National Child Labor Committee.

Look closely

- Find the looping machine. Can you see the ring of points where the loops are hung?
- Look at the children's hands and the work in front of them. How fine is the knitting?
- Look at their faces and clothing. How old do they seem to you?
- Find any stockings or knit goods nearby. What stage of finishing are they in?

Talk about it

1. Why does a knit edge have to be closed loop by loop rather than simply sewn like woven fabric?
2. Machines like the overlock and later automatic toe-closers replaced this hand work. Who benefited?
3. Hine photographed to change laws. What details here would have moved a reader in 1910?

Safety first. A serger is used only after a parent has watched you use it safely: unplug it to thread it or open its covers, keep fingers clear of the knife and needles, and never serge over pins. Pinking shears and rotary cutters are sharp: close the rotary blade every time you set it down, and carry shears closed, points down.

Six Seam Finishes and the Wash Test

Question: Which seam finish best prevents fraying through repeated washing? You will finish identical seam allowances six ways and measure fray loss after five washes.

You will need

- $\frac{1}{2}$ yd of a loosely woven cotton or linen that frays readily (the more it frays, the clearer the test)
- Pinking shears (if available), the sewing machine with zigzag, a serger (only if available and signed off), double-fold bias tape or a strip of lining for binding
- A mesh laundry bag, a ruler in mm and the 10× magnifier

Steps

1. **Hypothesis.** Rank the finishes from most to least fraying and predict the raw edge's percent loss.
2. Cut six pairs of 5×6 in rectangles on the grain. Sew each pair with a plain seam, $\frac{5}{8}$ in allowance, and press the allowances open (or together for serging).
3. Finish each seam a different way: (1) raw, (2) pinked, (3) zigzag along each edge, (4) turned under $\frac{1}{4}$ in and stitched, (5) Hong Kong bound with bias tape, (6) serged (or a French seam if you have no serger).
4. Measure the intact allowance width of each at three points. Photograph them.
5. Wash all six together in a mesh bag with a regular load five times, drying each time.
6. Measure the intact widths again, clip off loose threads, and calculate fray loss and percent lost for each.
7. **Conclude.** Which finishes stopped fraying, and which only slowed it? Which will you use on your Unit 9 garment, and why?
8. **Repeat round.** Try one more finish on a knit (jersey) seam: straight stitch versus narrow zigzag. Stretch both. Which pops?

Tips

- Count washes carefully; fraying grows with every wash.
- Zigzag just inside the raw edge, so the right swing of the needle goes over the edge.
- Keep the six samples as a reference card; you will be glad of it every time you start a garment.

Check your work

- ☐ I finished six identical seams six ways and changed nothing else.
- ☐ I measured before and after washing and calculated fray loss.
- ☐ I chose a finish for my own garment and justified it with data.

LAB NOTEBOOK

1. Draw a 3-thread overlock stitch around an edge, labeling the needle thread, upper looper and lower looper.
2. Tape in your six finished samples with their fray loss written beside each.
3. Write a one-page seam-finish guide: fabric type, best finish, why.

KEY FORMULAS

$$\text{fray loss} = \text{original allowance width} - \text{remaining intact width}$$

$$\text{fray loss} = \text{original allowance width} - \text{remaining intact width}$$

$$\text{thread needed} = \text{seam length} \times \text{thread-to-seam ratio}$$

$$\text{thread needed} = \text{seam length} \times \text{thread-to-seam ratio}$$

From history. The Merrow Machine Company's name became so tied to the edge stitch on blankets and patches that a “merrowed edge” is still the trade term for an overlocked border on an embroidered emblem.

WORKED EXAMPLES

Example 1. Six $\frac{5}{8}$ -in (15.9 mm) allowances were washed five times. The intact widths afterward were: raw 9.0 mm, pinked 13.5 mm, zigzag 15.0 mm, turned-and-stitched 15.9 mm, serged 15.9 mm. Find each fray loss and percent lost.

Show solution

1. Raw: $15.9 - 9.0 = 6.9$ mm $15.9 - 9.0 = 6.9$ mm, $6.9/15.9 = 43\%$ $6.9/15.9 = 43\%$.
2. Pinked: 2.4 mm (15%); zigzag: 0.9 mm (6%); turned-and-stitched and serged: 0 mm (0%).

Answer: Raw edges lost 43% of the allowance; enclosed and serged edges lost none.

Example 2. Assume a 4-thread serger uses about 16 m of thread for every meter of seam. A pair of pajama pants has 3.2 m of serged seams. How much thread is needed, and per cone if all four cones are used equally?

Show solution

1. Total: $3.2 \times 16 = 51.2$ m $3.2 \times 16 = 51.2$ m.
2. Per cone: $51.2 \div 4 = 12.8$ m $51.2 \div 4 = 12.8$ m.

Answer: About 51 m in all, about 13 m from each cone, on this assumed figure. That is why serger thread comes on big cones.

Example 3. A knit seam stretches from 10.0 cm to 11.2 cm as it is serged with differential feed at 1.0 (equal). At what differential setting, roughly, would you expect it to stay at 10.0 cm, if the setting is the ratio of front to back feed?

Show solution

1. Stretch ratio: $11.2/10.0 = 1.12$ $11.2/10.0 = 1.12$.
2. To push in the extra length, the front feed should move about 1.12 times as fast as the back: a setting near 1.1.

Answer: About 1.1; test on a scrap, since real behavior varies with the knit.

PRACTICE

1. Easy What does a serger do in one pass?

Show answer

Trims, sews and overcasts (finishes) the seam edge.

2. Easy Which family's company in Connecticut developed the overlock machine?

Show answer

The Merrows (Merrow Machine Company).

3. Easy Name two serger safety rules.

Show answer

Unplug before threading or opening covers; never serge over pins (also keep fingers from the knife area).

4. Medium A $\frac{5}{8}$ -in allowance is 11 mm intact after washing. Find the fray loss in mm and percent.

Show answer

$15.9 - 11 = 4.9$ mm $15.9 - 11 = 4.9$ mm, about 31%.

5. Medium What is the difference between a 3-thread and a 4-thread overlock?

Show answer

The 4-thread adds a second needle line (safety stitch) for a stronger seam.

6. Medium Why do knits need differential feed when serged?

Show answer

Feed dogs can stretch knit edges into a wavy "lettuce" edge; differential feed eases in the extra length.

7. **Medium** Name three seam finishes possible without a serger.

Show answer

Pinking, zigzag, turned-and-stitched, Hong Kong binding, French or flat-felled seams (any three).

8. **Hard** At 14 m of thread per meter of seam, how many meters of seam does one 1,000-m cone support in a 3-thread overlock (three cones used equally)?

Show answer

Thread per cone per meter of seam ≈ 4.67 m; $1,000/4.67 \approx 214$ m, $1,000/4.67 \approx 214$ m.

9. **Hard** Explain why pinking reduces fraying but does not stop it.

Show answer

The zigzag cut makes loosened yarns short and set at angles so fewer slip out, but the yarns are still free at the edge and can work loose in heavy washing.

10. **Hard** Which finish would you choose for a sheer cotton voile, a denim work apron and a jersey T-shirt? Why?

Show answer

Voile: French seam (enclosed, invisible). Denim: flat-felled (strong, flat, enclosed). Jersey: serged 4-thread or narrow zigzag (stretches with the knit).

11. **Challenge** A family has no serger. Plan the seams and finishes for a pair of woven cotton pajama pants and a knit T-shirt so both last for years.

Show answer

Pants: French or flat-felled seams, or plain seams with zigzag or turned-and-stitched finishes, hems double-folded. T-shirt: narrow zigzag or stretch stitch for seams, edges left unfinished (knits do not fray) or zigzagged to stop curling, twin-needle or zigzag hems.

COMMON MISTAKES

- Threading a serger in the wrong order. Most must be threaded loopers first, then needles; follow the manual's color-coded path.
- Serging over pins. It nicks the knife and can throw metal; pull pins well ahead of the foot.
- Leaving woven seam allowances raw. They fray inside the garment until the seam fails.

Make it a game • Count the Threads. Pull out store-bought garments and look at their serged seams with the magnifier. Each player guesses how many threads form each seam (2, 3, 4 or 5) before checking by tracing the threads with a pin. One point per correct guess; the player who finds a 5-thread safety stitch earns three.

7.5 PRESSING: HEAT, MOISTURE AND PRESSURE

OBJECTIVES

- Distinguish pressing from ironing and explain how heat, moisture, pressure and cooling set fabric for each fiber.
- Choose iron settings, press cloths and pressing tools (ham, seam roll, sleeve board, clapper, point presser) for a job.
- Measure crease sharpness with and without a clapper and convert temperatures between °F and °C.

Warm-up. Sew a short plain seam on a scrap and look at it before and after pressing it open. Describe the difference. Then look at a well-made jacket's shoulders and lapels: how could flat cloth have been shaped so smoothly?

WATCH

Pressing Tools for Bespoke Tailoring: Tailor's Hams & Sleeve Boards Explained – ISOT Lesson 2

[International School of Tailoring](#) · 8:05

https://www.youtube.com/watch?v=oh5GmRmT_lw

WHEN TO WATCH

After “The fabric science.” Watch how the tailor uses each pressing tool (hams, sleeve boards, clapper) and when he lets the cloth cool.

BACKUP VIDEO

Get great pressing results with a Tailor's Clapper

[Nancy's Notions](#) · 2:24

<https://www.youtube.com/watch?v=gF4nKm8umLA>

A quick demonstration of how a clapper sets a sharp crease.

KEY TERMS

pressing

Lifting and lowering the iron straight down onto the fabric, without sliding, to set seams and shapes.

press cloth

A cloth laid between iron and fabric to prevent shine, scorching and melting.

clapper

A smooth hardwood block pressed onto steamed fabric; the wood absorbs heat and moisture so the fabric cools under pressure and holds a sharp crease.

ironing

Sliding the iron back and forth to remove wrinkles from finished laundry; it can stretch fabric and seams if used during construction.

tailor's ham and seam roll

Firmly stuffed cushions used to press curved seams and darts (ham) and long seams without imprinting the allowances (roll).

glass transition

The temperature range at which a synthetic polymer softens and can be reshaped; heat-setting pleats in polyester works above it.

CORE IDEAS

The story. Tailors have always said that half of tailoring is pressing. In the old shops a tailor's goose, a heavy iron with a goose-neck handle, sat heating by the stove, and the tailor pressed every seam as he sewed, shaping wool over curved wooden boards and cushions. In London's Savile Row workshops, pressers still use heavy irons, wooden boards and clappers in the way their predecessors did a century ago. The skill made flat cloth curve over a shoulder and roll gently at a lapel.

How they figured it out. Pressers learned by experience the three ingredients that shape cloth, heat, moisture and pressure, and a fourth that sets it: cooling in place. A seam pressed with steam and then lifted while hot springs partly back; the same seam pressed and allowed to cool and dry under a clapper or hand stays crisp. Shaping a curve needs a curved surface beneath it (the ham), and pressing a seam on a flat board can print the edges of the allowance through to the right side, so tailors used a rounded seam roll beneath it.

The fabric science. Each fiber family responds to heat differently. In cotton and linen, heat and moisture break the hydrogen bonds between cellulose chains; pressed flat, the chains re-bond in their new position as the cloth cools and dries, which is why steam and a high setting work. Wool's keratin is shaped by steam, too, and its cross-links let a well-pressed crease hold; but too much heat yellows and shines it. Synthetics are thermoplastic: above their glass-transition range they soften and can be reshaped and set permanently, but a little higher they glaze and melt, so they need low heat and a press cloth. Typical iron settings run from about 110–135 °C (230–275 °F) for acetate and nylon, about 150 °C (300 °F) for silk, polyester and wool, to about 200 °C (400 °F) for cotton and 230 °C (445 °F) for linen; always test first on a scrap.

Pressing as you sew. The professional rule: press every seam before it is crossed by another. Press flat as sewn first (to set the stitches into the cloth), then open or to one side; press darts over a ham; press from the wrong side or with a press cloth on the right side; and never press over pins, which leave marks and can melt.

The studio lab. You will make a simple clapper (or borrow a smooth hardwood block) and test whether it sharpens creases in wool and cotton, measuring crease angles after 30 minutes. A press-cloth test on dark fabric will show you what shine looks like and how to prevent it.

PICTURE STUDY



Tailoring at Henry Poole and Co., Savile Row, British Ministry of Information photographer, 1944 · Photograph · Imperial War Museums, London (Crown copyright expired)

Image: [Wikimedia Commons](#), public domain

This wartime photograph shows a tailor at work in Henry Poole and Co., one of the oldest tailoring firms on Savile Row in London. Even under wartime rationing, the shop's craftsmen cut, sewed and pressed suits by hand, with heavy irons, boards and cloths little changed in a hundred years.

Look closely

- Find the iron or pressing tools. How heavy do they look?
- Find any boards, cushions or cloths on the bench. What might each be for?
- Look at how the garment is laid on the bench. Is it flat or shaped over something?
- Look at the tailor's posture and hands. What does he seem to be checking?

Talk about it

1. A tailor's heavy iron holds heat for a long time. Why would that be useful for pressing wool?
2. Why might a tailor press a seam many times during construction rather than once at the end?
3. What tools from this lesson do you see here, and which would you most like to own?

Safety first. Irons are hot: set the iron upright on its heel or on its rest, never face down, keep the cord where no one can trip on or pull it, and unplug it when you finish or leave the room. Steam burns too: keep hands clear of the steam vents and do not steam a garment while someone is wearing it. Use the fiber's setting and a press cloth on synthetics, which can melt.

STUDIO LAB

The Clapper Test and a Pressing Kit

Question: Does a clapper make a crease measurably sharper, and does it matter more for wool or for cotton? You will make or borrow a clapper and test creases, then build a simple pressing kit for the year.

You will need

- A smooth, unfinished hardwood block about $2 \times 3 \times 10$ in (maple or oak scrap), sandpaper
- Strips 2×6 in of wool (or a wool blend) and cotton, three of each
- The iron, a cotton press cloth, a spray bottle, the protractor and the index cards from Lesson 1.4
- An old towel and a tightly rolled magazine for a homemade seam roll

A HOMEMADE CLAPPER AND SEAM ROLL

Finished size: One clapper about $2 \times 3 \times 10$ in and one seam roll about 12 in long · About 45 minutes

Fabric and notions

- One smooth hardwood block (maple, oak or beech), unfinished
- Fine sandpaper (180–220 grit)
- A tightly rolled magazine or wooden dowel, an old cotton or wool towel, and strong rubber bands or string

How to make it

1. Sand all faces and edges of the block until smooth to the touch, rounding the long edges slightly so they will not mark fabric.
2. Wipe off dust. Do not varnish or oil it: bare wood must absorb heat and steam.
3. For the seam roll, roll the magazine or dowel tightly in the towel to a firm cylinder about 3 in across.
4. Tie or band it tightly at both ends and the middle, and tuck the ends in so the surface is smooth.

Fabric check: Use hard, close-grained wood; soft or resinous woods such as pine can leave sap marks. A cotton or wool towel makes the best roll cover; avoid synthetic fleece, which can melt under the iron.

Steps

1. **Hypothesis.** Predict which fiber the clapper helps more, and the crease angles after 30 minutes.
2. Fold each strip in half crosswise. Press three of each fiber at its correct setting with steam and a press cloth: (A) press and lift immediately; (B) press, then hold the iron on 10 seconds and lift; (C) press with steam, then immediately press the clapper on for 30 seconds.
3. Let all strips rest 30 minutes, then measure each crease's opening angle with the protractor.
4. Calculate the mean angle for each fiber and method and the percent reduction the clapper gave.
5. **Shine test.** On a scrap of dark wool or wool blend, press one area directly with a hot iron and the next through a press cloth. Compare in raking light.
6. **Conclude.** Did the clapper matter more for wool or for cotton? Why, using the chemistry of each fiber?
7. **Repeat round.** Sew a curved seam on a scrap and press it over a flat board and over the seam roll or a rolled towel. Which leaves allowance marks on the right side?
8. Store your pressing kit (clapper, roll, press cloth) together for Units 8–10.

Tips

- Press, do not iron: lift and lower.

- A ham can be made from two egg-shaped pieces of cotton and wool, stuffed hard with sawdust or wool scraps: a good extra project.
- Older presses and tailors call the act of cooling under the clapper “setting the press.”

Check your work

- ☐ I made or prepared a clapper and seam roll.
- ☐ I tested three pressing methods on two fibers and calculated results with units.
- ☐ I identified shine and prevented it with a press cloth.

LAB NOTEBOOK

1. Make an iron-setting chart for eight fibers in °F and °C, with notes on press cloths and steam.
2. Tape in your pressed strips in order of crease sharpness, labeled with angles.
3. Draw each pressing tool you own or made and write one job it does best.

KEY FORMULAS

$$^{\circ}\text{C} = \frac{5}{9}(^{\circ}\text{F} - 32), \quad ^{\circ}\text{F} = \frac{9}{5}^{\circ}\text{C} + 32$$

$$^{\circ}\text{C} = 95(^{\circ}\text{F} - 32), \quad ^{\circ}\text{F} = 59^{\circ}\text{C} + 32$$

$$\text{energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1,000}$$

$$\text{energy (kWh)} = 1,000 \text{power (W)} \times \text{time (h)}$$

From history. Before electric irons, households heated solid “sad irons” (sad meant heavy) on the stove and swapped them as they cooled. Electric irons appeared in the 1880s and spread with home electricity after 1900, and steam irons became common in the 1940s and 1950s.

WORKED EXAMPLES

Example 1. Convert the cotton setting of 400 °F and the silk setting of 150 °C.

Show solution

$$1. \frac{5}{9}(400 - 32) = \frac{5}{9}(368) = 204^{\circ}\text{C} \quad 95(400 - 32) = 95(368) = 204^{\circ}\text{C}$$

$$2. \frac{9}{5}(150) + 32 = 270 + 32 = 302^{\circ}\text{F} \quad 59(150) + 32 = 270 + 32 = 302^{\circ}\text{F}$$

Answer: 400 °F ≈ 204 °C; 150 °C ≈ 302 °F.

Example 2. A wool crease opened to 40° after 30 minutes when pressed with steam alone, and to 15° when pressed with steam and a clapper. If a perfectly sharp crease stays at 0°, by what percent did the clapper reduce the opening?

Show solution

$$1. \frac{40 - 15}{40} \times 100\% = 62.5\% \quad 40 - 15 \times 100\% = 62.5\%$$

Answer: The clapper reduced the crease opening by about 63%.

Example 3. A 1,200 W iron is on for 3 hours of sewing a week, heating about half the time. At \$0.16 per kWh, what does pressing cost per week and per 36-week school year?

Show solution

$$1. \text{Energy: } \frac{1,200 \text{ W} \times 1.5 \text{ h}}{1,000} = 1.8 \text{ kWh} \quad 1,000 1,200 \text{ W} \times 1.5 \text{ h} = 1.8 \text{ kWh}$$

$$2. \text{Week: } 1.8 \times \$0.16 = \$0.29 \quad 1.8 \times \$0.16 = \$0.29; \text{ year: } 36 \times \$0.29 \approx \$10.37 \quad 36 \times \$0.29 \approx \$10.37$$

Answer: About 29 cents a week and about \$10 a year; pressing is cheap and makes the biggest difference in finished work.

PRACTICE

1. **Easy** What is the difference between pressing and ironing?

Show answer

Pressing lifts and lowers the iron without sliding; ironing slides it. Pressing is used in construction to avoid stretching.

2. **Easy** Name the four things that shape and set fabric in pressing.

Show answer

Heat, moisture, pressure and cooling in place.

3. **Easy** What tool helps press a curved dart?

Show answer

A tailor's ham.

4. **Medium** Convert 230 °C to °F.

Show answer

446 °F.

5. **Medium** Convert 275 °F to °C.

Show answer

About 135 °C.

6. **Medium** Why does a press cloth prevent shine on dark wool?

Show answer

It keeps the hot soleplate from flattening and polishing the fiber surfaces and spreads heat and steam evenly.

7. **Medium** Explain how a clapper sets a sharp crease.

Show answer

Pressed onto steamed fabric, the wood absorbs heat and moisture so the cloth cools and dries under pressure, setting the new shape.

8. **Hard** Why can polyester pleats be set permanently with heat while cotton creases wash out?

Show answer

Polyester is thermoplastic: heated above its glass-transition range and cooled in shape, its chains lock there. Cotton creases are held by hydrogen bonds that water breaks again.

9. **Hard** A crease opens to 55° without a clapper and 22° with one. Find the percent reduction.

Show answer

60%.

10. **Hard** A 1,500 W iron runs 2 hours, heating 60% of the time. Find the energy and the cost at \$0.14 per kWh.

Show answer

1.8 kWh; about \$0.25.

11. **Challenge** You are pressing a seam in a cotton/polyester blend shirt. Choose the setting and method, and explain the trade-off with the chemistry of both fibers.

Show answer

Use the polyester (synthetic) setting or a little above, with steam and a press cloth: cotton would like more heat, but polyester would glaze or melt; steam and a clapper or cooling under the hand compensate for the lower heat.

COMMON MISTAKES

- Sliding the iron along seams during construction. It stretches them; lift and lower.
- Pressing over pins or basting knots. They leave marks and can melt or mar the soleplate.
- Using the cotton setting on a blend. The most heat-sensitive fiber decides the setting.

Make it a game · Setting Showdown. A parent holds up fabric scraps one at a time (cotton, linen, wool, silk, polyester, nylon, acetate, a blend). Players race to call the correct iron setting in °F or °C and whether to use a press cloth. One point for the setting, one for the press cloth, and a bonus for converting your answer to the other scale.

UNIT 7 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. **7 pts**
Tell the history of the sewing machine from Thimonnier to the Combination in five or six sentences.
2. **7 pts**
Name four parts of a machine needle and the job of the scarf.
3. **7 pts**
Convert 2.0 mm and 3.5 mm to SPI, and 14 SPI to mm.
4. **7 pts**
Describe the formation of a lockstitch in five steps.
5. **7 pts**
Bobbin thread shows on top of a seam. Diagnose the cause and give two fixes in the order you would try them.
6. **7 pts**
Use the $2(s + t)$ model to estimate thread for a 1.5 m seam with 2.5 mm stitches through 1.5 mm of fabric.
7. **6 pts**
Choose needle size and type for voile, a cotton jersey and canvas.
8. **7 pts**
Fabric breaks at 16.0 kg; plain seams at 12.0 kg; flat-felled at 15.2 kg. Find both efficiencies and explain the difference.
9. **6 pts**
A garment has four seams around the body. If each is sewn $\frac{1}{8}$ in too wide, how much smaller is the circumference?
10. **6 pts**
Explain why very short stitches can make a weaker seam.
11. **7 pts**
Describe how a serger forms an overlock seam and two serger safety rules.
12. **6 pts**
A $\frac{5}{8}$ -in (15.9 mm) allowance is 10.5 mm intact after washing. Find the fray loss and percent, and name two finishes that would prevent it.
13. **6 pts**
Convert 300 °F to °C and 200 °C to °F, and say which fibers each suits.
14. **7 pts**
Explain, fiber by fiber, how heat and moisture set cotton, wool and polyester when pressing.
15. **7 pts**
Short essay (5–7 sentences): Was the sewing machine good for working people? Use this unit's history and give a balanced answer.

UNIT PROJECT: A SEAM AND FINISH SAMPLE BOOK WITH A MACHINE LOG

Make a sample book of at least twelve labeled samples sewn on your own machine: tension ladder, stitch lengths (1.5, 2.5, 4 mm), plain seam pressed open and to one side, French seam, flat-felled seam, five seam finishes, a curved seam pressed over a seam roll, and a knit seam with straight versus zigzag stitch. Each sample has a card giving fabric, needle, thread, stitch settings and its test result.

Include your machine maintenance log for the unit, your parent's sign-off card for each tool, and a one-page guide to choosing seams and finishes for your Unit 9 garment.

LOOK FOR	WHAT IT MEANS
Safety and sign-off	Every tool was signed off by a parent; the log shows unplugging before maintenance.
Workmanship	Seams are straight, allowances accurate, and every sample is pressed properly.
Records	Each sample card states settings and test results completely.
Analysis	The guide uses lab data (seam efficiency, fray loss) to justify choices.
Improvement	First and final attempts are both included, showing progress.

ANSWER KEY

1. Thimonnier's chain-stitch machine (1830) was wrecked by tailors; Walter Hunt built a lockstitch machine with an eye-pointed needle around 1833–34 but did not patent it; Elias Howe patented his lockstitch machine on September 10, 1846; Isaac Singer patented a practical machine with a vertical needle and presser foot on August 12, 1851; lawsuits followed, and in 1856 the makers formed the Sewing Machine Combination, a patent pool paying Howe royalties; Singer's installment plan brought machines into homes.
2. Shank, shaft, groove, scarf, eye, point (any four). The scarf lets the hook come close enough to catch the thread loop.
3. 12.7 and 7.3 SPI; 1.8 mm.
4. Needle descends with top thread; a loop forms as it rises; the hook catches the loop and carries it around the bobbin; the take-up lever tightens the stitch; the feed dogs move the fabric one stitch.
5. Top tension too tight relative to bobbin. Rethread (foot up) and clean lint; then lower the top tension gradually.
6. $\text{Ratio } 2(4.0)/2.5 = 3.22(4.0)/2.5 = 3.2$; $1.5 \times 3.2 = 4.8 \text{ m}$. $1.5 \times 3.2 = 4.8 \text{ m}$.
7. Voile: 60/8–70/10 sharp or universal. Jersey: 80/12 ballpoint. Canvas: 100/16 denim/jeans.
8. 75% and 95%. The flat-felled seam spreads load across two stitch rows and folded layers, so it nearly matches the fabric.
9. $4 \times 2 \times \frac{1}{8} = 1 \text{ in}$; $4 \times 2 \times 81 = 1 \text{ in}$
10. Closely spaced needle holes perforate the fabric along the seam line, so it tears there before the extra thread can help.
11. Needles sew through the fabric while loopers carry threads around the edge, interlocking with the needle threads, and a knife trims the edge just ahead. Unplug to thread or open; never serge over pins; keep fingers from the knife.
12. 5.4 mm, 34%; turned-and-stitched, serged, bound, French or flat-felled (any two).
13. $\approx 149^\circ\text{C}$ (silk, wool, polyester); 392°F (cotton).
14. Cotton: heat and moisture break hydrogen bonds, which re-form as the cloth cools and dries. Wool: steam softens keratin; cross-links and cooling hold the new shape. Polyester: heat above glass transition softens chains, which lock on cooling (heat-setting); too hot melts it.
15. A strong essay notes early fears and the wrecking of Thimonnier's shop, Hunt's hesitation, and garment-factory hardships, against cheaper clothing, new paid work, faster home sewing, the installment plan's spread to families, and service work like the Red Cross rooms; it reaches a reasoned judgment.

PATTERNS AND FIT

A pattern is a garment's blueprint: flat paper shapes that, cut from cloth and sewn, wrap a three-dimensional person. Until the 1860s most home sewers drafted their own or copied an old garment; then Ebenezer and Ellen Butterick began selling tissue-paper patterns graded in sizes, and home dressmaking was transformed. This unit teaches you to read a pattern envelope and its symbols, choose a size from measurements, lay out pieces on the grain and calculate yardage, test a pattern in muslin and adjust it, and finally draft and grade a simple pattern of your own.

Measuring and fitting are done with care and modesty. Measurements are taken over light clothing by a parent (for older students, the father for a son or the mother for a daughter), recorded for fit only, and never discussed as good or bad numbers. Fitting is about comfort, ease of movement and a garment that suits its use; every body is different, and a pattern is adjusted to the person, never the other way round. The unit ends with a personal pajama-pants pattern, drafted, fitted, graded and ready for Unit 9.

PREREQUISITES

- Unit 7: machine use, seams and pressing, with parent sign-off
- Comfortable with fractions of an inch, scale drawings and simple proportion
- A 60-inch tape measure, a clear ruler, pattern paper (or wrapping paper), muslin or an old flat sheet

MASTERY CHECKLIST

- ☐ I can tell the story of the Butterick graded pattern and read every part of a pattern envelope.
- ☐ I can take measurements modestly and accurately and choose a pattern size from them.
- ☐ I can calculate wearing and design ease from finished garment measurements.
- ☐ I can read pattern symbols, lay out pieces on grain, and calculate yardage for different fabric widths.
- ☐ I can sew a muslin, read fitting wrinkles, and make lengthen, shorten, widen and narrow adjustments.
- ☐ I can draft a simple pattern from a garment or measurements and grade it to another size.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Pattern paper, a French curve and a clear 2 × 18 in ruler:** Tissue or medical exam-table paper works for pattern paper; a flexible curve ruler helps with crotch and armhole curves.
- **Unbleached muslin or old flat sheets:** Muslin is the classic test fabric. Thrift-store flat sheets give several yards cheaply.
- **A simple commercial pattern:** Any envelope pattern for elastic-waist pants, a skirt or a vest, from a fabric store or thrift store, for practice reading envelopes and symbols.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

8.1 Butterick's Graded Pattern	3 sessions of 50 minutes
8.2 Measuring and Ease	3 sessions of 50 minutes
8.3 Grain, Symbols and Layout	3 sessions of 50–90 minutes
8.4 The Muslin and the Fitting	3 sessions of 50–90 minutes
8.5 Drafting and Grading: Hannah's Coat Every Year	3 sessions of 50–90 minutes

8.1 BUTTERICK'S GRADED PATTERN

OBJECTIVES

- Tell how Ebenezer and Ellen Butterick introduced graded tissue-paper patterns in 1863 and how patterns changed home sewing.
- Read every part of a pattern envelope: views, size chart, finished measurements, yardage chart, notions and suggested fabrics.
- Calculate yardage and cost for different sizes and fabric widths.

Warm-up. Look at a commercial pattern envelope (or one online at a pattern company's site). Without reading the back, guess how much fabric the main view needs. Then turn it over and find the answer. How close were you?

WATCH

Sewing How To: Reading a Sewing Pattern – The Envelope | Hobby Lobby®

HobbyLobby · 3:18

<https://www.youtube.com/watch?v=Uzkshlv06OE>

WHEN TO WATCH

Watch once through, then again with your pattern envelope in hand, finding each part as the presenter names it.

BACKUP VIDEO

How to Read a Sewing Pattern Envelope | Beginner Sewing FAQs with Janet Pray

Craftsy · 5:53

<https://www.youtube.com/watch?v=9jlbvkaWLSs>

A second guide to the envelope's sizes and yardage chart.

KEY TERMS

graded pattern

A pattern made in a series of sizes, each enlarged or reduced from a base size by set amounts.

size chart

The table of body measurements for each pattern size, used to choose a size.

yardage chart

The table of fabric needed for each view and size in different fabric widths, with and without nap.

pattern envelope

The packet holding a commercial pattern; its back gives sizes, measurements, fabric amounts, notions and suggested fabrics.

finished garment measurements

The measurements of the completed garment itself, larger than the body by the amount of ease.

notions

The small supplies a pattern needs besides fabric: thread, buttons, zipper, elastic, interfacing, trim.

CORE IDEAS

The story. In 1863 Ebenezer Butterick was a tailor in Sterling, Massachusetts. His wife, Ellen Augusta Pollard Butterick, sewed for their family and found it hard to cut a good garment from the one-size patterns printed in magazines. Together they began making patterns in a range of sizes on thin tissue paper, first for men's and boys' shirts and suits. They sold so well that the Buttericks moved to New York, founded a company, and by the 1870s were selling millions of patterns a year and publishing a fashion and sewing magazine, *The Delineator*. Other makers, including James McCall, followed. For a century, most American families' best clothes began as a tissue pattern spread on a dining-room table.

How they figured it out. A one-size pattern forces every sewer to redraw it. The Buttericks' idea was grading: drafting a base size carefully, then enlarging and reducing it by consistent amounts at the right places, the chest, waist, length and shoulders, so that each size fit a different set of measurements. Printing on cheap tissue made patterns light enough to mail and fold, and a printed guide sheet told the sewer how to lay out, cut and assemble. The same envelope still organizes nearly every commercial pattern sold.

The fabric science (of an envelope). The back of a pattern envelope is a compact technical document. The *size chart* lists body measurements for each size: choose by measurements, never by the size you buy in stores, because pattern sizing differs. *Finished*

garment measurements, sometimes printed on the tissue itself, tell you how much ease is designed in. The *yardage chart* gives fabric needed for each view and size in common widths (45 in and 60 in), with or without nap. *Notions* and *suggested fabrics* tell you what else to buy and which fabrics will drape as designed: a pattern drawn for soft rayon will look stiff in canvas.

Width and yardage. Wider fabric usually needs fewer yards, but not in exact proportion, because pattern pieces fit across the width in whole numbers. A pair of pants whose leg pieces fit side by side on 60-in fabric but not on 45-in fabric may need almost twice the yardage on the narrower goods. Always read the yardage chart for your actual width.

The studio lab. You will dissect a commercial pattern: identify every part of the envelope, take your family's measurements as practice in reading (not judging) a size chart, inventory the tissue pieces and guide sheet, and calculate yardage and cost for the same garment in two widths and two fabrics.

PICTURE STUDY



Woman Sewing by Lamplight, Jean-François Millet, 1852 · Oil on canvas · Image from Wikimedia Commons, public domain
Image: [Wikimedia Commons](#), public domain

Millet painted the evening work of peasant households, when the day's outdoor labor was done and clothes were made and mended by lamplight. This was home sewing before graded patterns: every garment was cut by eye, by an old garment, or by a pattern the sewer drew herself.

Look closely

- Find the lamp. How does it light her work, and what is left in shadow?
- Look at her hands. Is she sewing by hand, and what kind of stitch might she be making?
- Find any pieces of cloth around her. Is she making something new or mending?
- Notice her posture. How long might she sit like this?

Talk about it

1. Without a printed pattern, how might she have cut a new shirt for her husband?
2. What would a graded pattern have saved her in time and fabric?
3. Why might Millet think this quiet evening work worth a painting?

Safety first. Measuring is done over light clothing by a parent (for older students, the father for a son or the mother for a daughter), and the numbers are written down for fit only, never compared or judged. Tissue patterns tear easily: handle them flat and fold them back along their original creases. Count pins at the end of the session.

Dissecting a Pattern

Question: Can you read a commercial pattern completely before cutting a single piece? You will analyze an envelope, inventory its pieces, choose a size from measurements and price the garment two ways.

You will need

- A commercial pattern for elastic-waist pants, a simple skirt or a vest (new or thrift store, uncut if possible)
- A 60-in tape measure, your lab notebook and a calculator
- Prices for two fabrics in 45-in and 60-in widths (from a store visit or a website)

Steps

1. **Hypothesis.** Guess the size you will need and the yardage for the main view before reading anything.
2. Copy the envelope's information into your notebook: views, description, suggested fabrics, notions, size chart, finished measurements and the yardage line for your view.
3. With a parent, take the three or four body measurements the size chart uses, over light clothing, and record them for fit only.
4. Choose the size by the chart. If measurements fall in different sizes, note which measurement matters most for this garment (hips for pants, chest for a vest) and choose by it.
5. Open the pattern and inventory every tissue piece against the guide sheet. Note which pieces your view uses.
6. Calculate yardage and total cost for your size in two fabrics and two widths, including notions.
7. **Conclude.** Which fabric and width is the best value? How close was your guess?
8. **Repeat round.** Do the same calculation for a younger sibling's or parent's size, and compare costs.

Tips

- Iron tissue pieces flat with a dry iron on a low setting before using them; steam makes tissue wrinkle.
- Keep the guide sheet in a page protector; you will refer to it at every step.
- Write your size and the date on the envelope so you know which lines you used.

Check your work

- ☐ I recorded every part of the envelope accurately.
- ☐ I chose a size by measurement and explained my choice.
- ☐ I calculated yardage and cost for two widths and two fabrics.

LAB NOTEBOOK

1. Make a labeled copy of the envelope back with each part named.
2. Draw the pattern pieces for your view in miniature and label each.
3. Start a measurement card (kept privately in your notebook) with the date of each measurement.

KEY FORMULAS

$$\text{cost} = \text{yards} \times \text{price per yard}$$

$$\text{equivalent yardage (approximate)} = \text{yards} \times \frac{\text{original width}}{\text{new width}}$$

$$\text{equivalent yardage (approximate)} = \text{yards} \times \frac{\text{new width}}{\text{original width}}$$

From history. Ellen Butterick is often credited with the original idea of graded patterns, and the company long honored her as its co-founder. *The Delineator*, the Butterick magazine, became one of the most widely read women's magazines in America in the early 1900s.

WORKED EXAMPLES

Example 1. A vest needs $1\frac{1}{8}$ yd of 45-in fabric or $\frac{7}{8}$ yd of 60-in fabric. The 45-in fabric costs \$9.98 per yard and the 60-in costs \$13.49. Which is cheaper for this vest?

Show solution

1. 45-in: $1.125 \times \$9.98 = \$11.23$
 $1.125 \times \$9.98 = \$11.23$
2. 60-in: $0.875 \times \$13.49 = \$11.80$
 $0.875 \times \$13.49 = \$11.80$

Answer: The 45-in fabric, by 57 cents: compare total cost, not price per yard.

Example 2. A pattern gives $2\frac{3}{4}$ yd of 45-in fabric. You find a fabric only 36 in wide that the chart does not list. Estimate the yardage by the area ratio, and say why you should add extra.

Show solution

1. $2.75 \times \frac{45}{36} = 3.44$ yd
 $2.75 \times \frac{45}{36} = 3.44$ yd
2. Pieces fit across the width in whole numbers, so narrower fabric may waste more; round up and add about $\frac{1}{4}$ yd.

Answer: About $3\frac{1}{2}$ yd; buy $3\frac{3}{4}$ yd to be safe, or lay out the pieces on paper first (Lesson 8.3).

Example 3. A garment's chest measures 42 in finished. A person's chest measures 38 in. How much ease is designed in? If the size chart says size 14 is for 36 in and size 16 for 38 in, and you are 38 in, which size do you choose?

Show solution

1. Ease: $42 - 38 = 4$ in
 $42 - 38 = 4$ in
2. Choose the size whose body measurement matches: size 16.

Answer: 4 in of ease; size 16 by the chart, regardless of the size bought in stores.

PRACTICE

1. **Easy** In what year did the Buttericks begin selling graded patterns, and where did Ebenezer work as a tailor?

Show answer

1863; Sterling, Massachusetts.

2. **Easy** Name five things printed on the back of a pattern envelope.

Show answer

Size chart, finished measurements, yardage chart, notions, suggested fabrics (also views and descriptions).

3. **Easy** Why choose a pattern size by measurements rather than ready-to-wear size?

Show answer

Pattern sizes follow their own charts and often differ from store sizes.

4. **Medium** $2\frac{3}{8}$ yd at \$7.49 per yard costs how much?

Show answer

$2.375 \times 7.49 \approx \$17.79$
 $2.375 \times 7.49 \approx \$17.79$

5. **Medium** Estimate yards of 54-in fabric equivalent to 3 yd of 45-in.

Show answer

$3 \times \frac{45}{54} = 2.5$ yd
 $3 \times \frac{45}{54} = 2.5$ yd (check a layout).

6. **Medium** A finished hip measurement is 44 in and the body hip is 40 in. Find the ease.

Show answer

4 in.

7. **Medium** What is the difference between a body measurement and a finished garment measurement?

Show answer

The body measurement is the person; the finished measurement is the garment, larger by the ease.

8. **Hard** Pants need $2\frac{5}{8}$ yd of 45-in or $1\frac{5}{8}$ yd of 60-in. Explain why the difference is larger than the width ratio predicts.

Show answer

Width ratio predicts about 2 yd; but on 60-in fabric the leg pieces fit side by side while on 45-in they must be laid end to end, nearly doubling the length.

9. **Hard** A family sews matching pajama pants: sizes needing $2\frac{1}{4}$, $2\frac{5}{8}$ and 3 yd of 45-in flannel at \$6.99 per yard, plus 1 yd elastic each at \$0.89 per yard. Find the total cost.

Show answer

Fabric $7.875 \times 6.99 \approx \$55.05$; elastic $7.875 \times 6.99 \approx \$55.05$; elastic \$2.67; total about \$57.72.

10. **Hard** Why does a pattern list suggested fabrics, and what goes wrong if you ignore them?

Show answer

The design depends on drape, weight and stretch; the wrong fabric hangs differently, may not fit (especially knit patterns sewn in woven fabric), or makes a garment stiff or limp.

11. **Challenge** Before graded patterns, how did families get well-fitting clothes? What did the Buttericks' idea change for a mother sewing for six children of different sizes?

Show answer

They drafted their own patterns, copied old garments, used one-size magazine diagrams, or hired tailors and dressmakers. Graded patterns let her buy one pattern and cut each child's size accurately, saving time, fabric and guesswork.

COMMON MISTAKES

- Choosing a pattern size by store size. Use the chart.
- Buying fabric before checking the yardage for your exact width and view.
- Ignoring nap. One-way prints, corduroy and velvet need “with nap” yardage.

Make it a game · Envelope Scavenger Hunt. A parent calls out a detail (“How many buttons for view B?” “Yardage for size 12 in 60-in fabric?” “Which fabrics are suggested?”). The first player to find and read the answer from a pattern envelope scores a point. Use two or three different envelopes so players learn to read any company's format.

8.2 MEASURING AND EASE

OBJECTIVES

- Take accurate body measurements modestly and record them for fit only.
- Distinguish wearing ease from design ease and explain why garments are larger than the body.
- Measure finished garments flat and calculate their ease against body measurements.

Warm-up. Take a favorite, comfortable shirt or pair of pants and lay it flat. Measure straight across the chest or hips and double it. Then guess: how much bigger is it than the person who wears it, and why does it need to be?

WATCH

What is Ease? Understand Ease in a Dressmaking Pattern

Made to Sew • 6:10

<https://www.youtube.com/watch?v=PCByJe5cgTc>

WHEN TO WATCH

After “The fabric science.” Pause at each kind of ease and write its definition in your notebook.

KEY TERMS

body measurement

A measurement of the person, taken over light clothing with the tape snug but not tight.

design ease

Extra fullness the designer adds beyond wearing ease to create a style: a loose smock, a full skirt, a relaxed pajama leg.

measurement card

A dated, private record of a person's measurements kept for sewing.

wearing ease

The minimum extra room a garment needs so the wearer can breathe, sit, reach and move.

negative ease

A garment smaller than the body, possible only in stretch knits such as socks and ribbed cuffs.

rise

In pants, the distance from the crotch seam to the waist, front or back.

CORE IDEAS

The story. Tailors have measured customers for as long as clothing has been made to order. In seventeenth-century Dutch workshops the tailor took measurements with a strip of paper or parchment, notching it for each length, and later tailors adopted the cloth or paper tape marked in inches. Good tailors measured quickly, quietly and respectfully, over the customer's clothing, wrote the numbers in a book, and never remarked on them. That is the standard for this course. Scripture's first garments were made by God Himself for Adam and Eve, coats of skins to clothe them; clothing that fits and covers is a mercy, and measuring is part of making it.

How they figured it out. Experience taught tailors that a garment the exact size of the body cannot be worn: you could not breathe, sit or lift your arms. Garments need *wearing ease*: commonly a few inches at the chest and hips of a woven garment and an inch or so at the waist, more for coats worn over other clothes. Designers then add *design ease* for the style. Pattern companies print finished garment measurements so sewers can see the total ease and decide whether it suits them. Knits can have less ease, even negative ease, because they stretch.

The fabric science. Ease depends on the fabric and the body's movement. Wovens stretch little, so they need more ease; knits stretch and recover, so they need less. Bending and reaching lengthen the back and the seat by several inches, which is why pants need more back rise than front and why shirts need room across the back. Fit is about comfort and use: a work shirt needs room to reach, pajama pants need room to sit and sleep, a vest worn over a shirt needs room for the shirt.

Measuring well. Measure over light, close clothing (a T-shirt and thin, close-fitting pants, or the person's usual undergarments plus a light layer), standing naturally, with the tape level all around and snug but not pulling. A parent measures (for older students, the

father for a son or the mother for a daughter), says the numbers quietly, and the student writes them down. Common measurements are chest, waist, hip, back-waist length, shoulder width, arm length, inseam, outseam and height. Measurements are information for making clothes that fit, nothing more: they are never called good or bad, never compared, and they change as people grow, which is why the card is dated.

The studio lab. You will make your own measurement card, then measure three garments you find comfortable, laid flat, and calculate their ease at each point. The result is your personal ease preference, the most useful number in this unit.

PICTURE STUDY



The Tailor's Workshop, Quiringh van Brecklenkam, 1661 · Oil on canvas · Rijksmuseum, Amsterdam

Image: [Wikimedia Commons](#), public domain

Brecklenkam painted Leiden's tailors at work again and again. Dutch tailors sat cross-legged on a raised table by the window for the best light, sewing garments made to measure for customers in the town.

Look closely

- Find the tailors sitting on the table. Why would they sit cross-legged up there?
- Find the window. How does the light fall on their work?
- Look for tools: shears, thread, a measure, garments hanging. What can you identify?
- Find anyone who is not sewing. What might that person be doing?

Talk about it

1. A seventeenth-century tailor measured with strips of paper notched for each length. What would be the advantages and drawbacks compared with a tape?
2. How would a tailor make sure a coat had enough room to move without a printed pattern?
3. What does this workshop suggest about how long a made-to-measure coat took?

Safety first. Measurements are taken over light clothing, by a parent (for older students, the father for a son or the mother for a daughter), quickly and quietly; they are written down for fit only and never discussed as good or bad or compared with anyone. Keep the measurement card private in your notebook.

STUDIO LAB

Your Measurement Card and Your Ease Preference

Question: How much ease do you actually prefer in the clothes you find comfortable? You will make a dated measurement card and measure three favorite garments to find out.

You will need

- A 60-in tape measure, a parent to measure, your lab notebook
- Three comfortable woven garments you wear often (a shirt, pants or pajama pants, a vest or jacket)
- A flat table and a clear ruler

Steps

1. **Hypothesis.** Guess how many inches of ease your favorite shirt has at the chest and your favorite pants at the hip.
2. With your parent measuring over light clothing, record chest, waist, hip, back-waist length, shoulder width, arm length, inseam and height. Date the card and keep it private.
3. Lay each garment flat, smoothing without stretching. Measure across the chest or hip, the waist (relaxed, for elastic), and the length.
4. Double the flat widths to get circumferences, and subtract your body measurements to find ease at each point.
5. Make a table of ease by garment and location, and find your mean preferred ease for shirts and for pants.
6. **Conclude.** Are you more comfortable with more or less ease than you guessed? Does it differ between garment types?
7. **Repeat round.** Measure one garment you do not find comfortable. Where is the ease too little or too much?

Tips

- Measure each body point twice; if the readings differ by more than $\frac{1}{4}$ in, measure a third time.
- Tie a narrow elastic or ribbon at the natural waist before measuring; it marks the level for every other measurement.
- Your ease preference will guide every pattern size you choose from now on.

Check your work

- ☐ I made a complete, dated measurement card, taken modestly by a parent.
- ☐ I calculated ease at three or more points on three garments.
- ☐ I stated my ease preferences with numbers.

LAB NOTEBOOK

1. Draw a simple figure outline and mark where each measurement is taken (no numbers on the drawing).
2. Make your ease table and a bar chart of ease by garment.
3. Write a three-sentence rule for yourself about choosing pattern sizes using ease.

KEY FORMULAS

ease = finished garment measurement – body measurement

ease = finished garment measurement – body measurement

circumference from a flat garment = $2 \times$ flat width

circumference from a flat garment = $2 \times$ flat width

From history. The standard sizes of ready-made clothing came late. In the 1930s and 1940s the U.S. Department of Agriculture measured thousands of women and children to develop sizing standards for the clothing industry, and manufacturers and pattern companies have revised their size charts many times since. That is one reason store sizes and pattern sizes rarely match.

WORKED EXAMPLES

Example 1. A comfortable woven shirt laid flat measures 21 in across the chest. The wearer's chest is 37 in. Find the ease.

Show solution

1. Circumference: $2 \times 21 = 42$ in $2 \times 21 = 42$ in.
2. Ease: $42 - 37 = 5$ in $42 - 37 = 5$ in.

Answer: 5 in of ease at the chest: wearing ease plus some design ease for a relaxed fit.

Example 2. Pajama pants should have about 6 in of ease at the hip. A person's hip is 38 in. What finished hip measurement should the pattern have, and what flat width across the hips?

Show solution

1. Finished hip: $38 + 6 = 44$ in $38 + 6 = 44$ in.
2. Flat width: $44 \div 2 = 22$ in $44 \div 2 = 22$ in.

Answer: 44 in finished, 22 in across when laid flat.

Example 3. A rib-knit cuff measures 7 in around unstretched; the wrist is $6\frac{1}{2}$ in. Find the ease, and explain the sign.

Show solution

1. $7 - 6.5 = 0.5$ in $7 - 6.5 = 0.5$ in.
2. Positive ease means the cuff is larger than the wrist; a knit cuff could even have negative ease (smaller than the wrist) and still go on, because it stretches.

Answer: $\frac{1}{2}$ in positive ease; negative ease is possible only in stretch knits.

PRACTICE

1. **Easy** Define wearing ease and design ease.

Show answer

Wearing ease: minimum room to move and breathe. Design ease: extra fullness for style.

2. **Easy** Who takes measurements in this course, and over what?

Show answer

A parent (for older students, the father for a son or the mother for a daughter), over light clothing.

3. **Easy** Why is the measurement card dated?

Show answer

Measurements change as people grow; the date tells which numbers are current.

4. **Medium** A flat skirt measures 20 in across the hip; the wearer's hip is 37 in. Find the ease.

Show answer

3 in.

5. **Medium** A woven vest needs 3 in of chest ease over a 36-in chest. Find the finished chest measurement.

Show answer

39 in.

6. **Medium** Why do knits need less ease than wovens?

Show answer

Knits stretch and recover, so the fabric itself gives room for movement.

7. **Medium** Why does the back of pants need more length (rise) than the front?

Show answer

Sitting and bending stretch the seat and back; extra back rise keeps the pants from pulling down.

8. **Hard** A coat must fit over a sweater $1\frac{1}{2}$ in thick in total circumference added and still have 4 in of wearing ease over a 38-in chest. Find the finished chest.

Show answer

$38 + 1.5 + 4 = 43.5$ in $38 + 1.5 + 4 = 43.5$ in

9. **Hard** Three comfortable shirts have chest ease of 4, 5½ and 6 in. Find the mean, and say how you would use it when choosing a pattern size.

Show answer

Mean 5.17 in. Compare the pattern's finished chest minus your chest with about 5 in; choose the size that gives ease near your preference.

10. **Hard** Why should the tape be snug but not tight, and level all around?

Show answer

A tight tape compresses and under-measures; a slanted tape measures a longer, diagonal path and over-measures.

11. **Challenge** Explain in your own words why this course never calls measurements good or bad, and how a tailor's respect for a customer shows in the way he measures.

Show answer

Measurements are facts for making a garment fit, not judgments of worth; bodies differ as God made them and change with age. A good tailor measures quickly, quietly, over clothing, records without comment and makes the garment serve the person.

COMMON MISTAKES

- Measuring over bulky clothing. It adds inches that the garment will not need.
- Pulling the tape tight to “be accurate.” Snug, not tight.
- Treating measurements as anything but tools for fit. They are information, not a judgment.

Make it a game · Guess the Ease. A parent lays out five garments of different styles (a T-shirt, a dress shirt, a sweatshirt, pajama pants, a vest) with the owner's name. Players guess the chest or hip ease of each to the nearest inch, then measure. Closest guess on each garment scores a point; a guess within ½ in scores two.

Scripture. “Unto Adam also and to his wife did the LORD God make coats of skins, and clothed them.” (Genesis 3:21, KJV)

The first garments in Scripture were made by God to clothe and cover. Clothing that fits and covers well is an echo of that care.

8.3 GRAIN, SYMBOLS AND LAYOUT

OBJECTIVES

- Read pattern symbols: grainline, place-on-fold, notches, dots, cutting and stitching lines, lengthen/shorten lines.
- Straighten fabric grain and lay out pattern pieces on grain, with and without nap.
- Plan a layout to scale, calculate yardage and fabric efficiency, cut accurately and transfer markings.

Warm-up. Tear a strip off the end of a piece of cotton (snip the selvage and tear across). Does the torn edge run straight across the weave? Now cut a strip with scissors by eye beside it. Which edge follows the crosswise grain?

WATCH

What is the grain of fabric? What is the grainline? And how to find and use it! - Sewing Terminology.

Evelyn Wood · 8:24

<https://www.youtube.com/watch?v=xmkkfsYfyko>

WHEN TO WATCH

After “The fabric science.” Watch how the presenter finds the grainline and measures from the arrow to the selvage at both ends.

BACKUP VIDEO

Learn to Sew: How to Lay Out Your Pattern

Sew Make Do · 2:22

<https://www.youtube.com/watch?v=NRX5kE70Mcc>

A short lesson on laying out pattern pieces on folded fabric.

KEY TERMS

grainline arrow

The long arrow on a pattern piece that must lie parallel to the lengthwise grain (the selvage).

notches and dots

Small triangles and circles on pattern edges and inside pieces that match pieces together and mark details; they are transferred to the fabric.

off-grain

Fabric whose crosswise threads are not at right angles to the lengthwise threads; garments cut off-grain twist and hang badly.

place on fold

A bracketed arrow meaning the piece's edge lies exactly on the folded edge of the fabric, so it is cut double width in one piece.

nap

A one-way surface or design (pile, brushed fabric, one-way print) that looks different upside down; all pieces must point the same way.

fabric efficiency

The percent of the fabric area used by pattern pieces in a layout.

CORE IDEAS

The story. Tailors cutting expensive wool always knew that cloth wasted on the cutting table was money lost, and that cloth cut crooked would hang crooked forever. Early cutting books printed diagrams showing exactly how a coat's pieces should nest on a length of cloth. The pattern envelope's guide sheet carries on the tradition with its cutting layouts: diagrams for each view, size and fabric width, showing which pieces go on the fold, which are cut twice and which way each grainline runs.

How they figured it out. Cutters learned that the lengthwise grain is strongest and most stable, so pieces that must hang straight (a pant leg, a shirt front) are laid with their length along it. Pieces cut on the bias drape and stretch, which tailors use deliberately for collars, bindings and skirts that flare. Pattern makers mark the intended grain with an arrow; the sewer measures from each end of the arrow to the selvage, adjusting until the two measurements match, and only then pins.

The fabric science. Woven fabric can be pulled off-grain in finishing, so that the crosswise threads slant. A garment cut from off-grain fabric twists after washing as the yarns relax, especially pant legs and shirt side seams. To check, clip the selvage and tear across, or pull a single crosswise thread and cut along the line it leaves; then fold the fabric selvage to selvage and see whether the

cut ends meet squarely. Many cottons can be gently pulled back on grain on the diagonal, especially while damp; finishes on some fabrics prevent it. Prints are sometimes printed off-grain: then follow the grain, not the print, for a garment that hangs well.

Layout and marking. Lay the fabric smooth on a large table, folded as the guide sheet shows. Place the large pieces first, all grainlines checked, all nap pointing one way when needed, then fit smaller pieces into the gaps. Pin or weight the pieces, cut with long, smooth strokes on the cutting line (cutting notches outward), and transfer every dot and notch with tailor's chalk, a tracing wheel and paper, or tailor's tacks before removing the tissue.

The studio lab. You will draw your Unit 8 pattern pieces to a 1:8 scale on graph paper, plan layouts for 45-in and 60-in fabric, calculate yardage and efficiency, then straighten a length of muslin and cut and mark the real pieces for your Lesson 8.4 muslin.

PICTURE STUDY



A Tailor with Two Assistants in His Workshop, Quiringh van Brekelenkam, c. 1660s · Oil on panel · Philadelphia Museum of Art
Image: [Wikimedia Commons](#), public domain

Brekelenkam returned to the tailor's shop many times. Here a master and his assistants work together. In such shops the master usually measured customers and cut the cloth himself, the most skilled and costly step, while journeymen and apprentices did much of the sewing.

Look closely

- Find the cutting table or the master's work. Is anyone cutting or marking cloth?
- Find the shears. How large are they?
- Look at how the work is divided among the three men.
- Find any garment pieces or patterns hanging or lying about.

Talk about it

1. Why would the master keep the cutting for himself?
2. How might he have laid out pieces to waste as little expensive wool as possible?
3. What mistakes in cutting could an apprentice not undo with sewing?

Safety first. Use fabric shears only on fabric, carried closed and points down. If you use a rotary cutter, use a mat and a ruler, cut away from your body, and close the blade every time you set it down. Pins go in a pincushion or magnetic dish, counted out and back in.

STUDIO LAB

Layout to Scale, Then Cut the Muslin

Question: How much fabric does your garment really need on 45-in and 60-in widths, and how efficient is your layout? You will plan layouts to scale and then straighten, lay out, cut and mark a real muslin.

You will need

- Your chosen pattern pieces for pajama pants (from a commercial pattern in your size, or from Lesson 8.5 if you draft first)
- Graph paper (¼-in squares), a ruler and scissors for paper
- 2½ yd of unbleached muslin or an old flat sheet, prewashed and pressed
- Fabric shears, pins or pattern weights, tailor's chalk or a tracing wheel and tracing paper

Steps

1. **Hypothesis.** Predict the yardage on each width and the efficiency of your best layout.
2. Draw each pattern piece to 1:8 scale on graph paper (each ¼-in square = 2 in) and cut them out. Mark grainlines.
3. Draw two rectangles to scale: 45-in fabric folded and 60-in fabric folded, each 3 yd long. Arrange the paper pieces on each, grainlines parallel to the selvage, as tightly as you can. Trace the layout.
4. Measure the length used on each and convert to yards. Estimate efficiency using the pieces' areas.
5. Straighten the muslin: clip and tear across each end, fold selvage to selvage, and check that the ends meet squarely. Pull diagonally to correct if needed and press.
6. Lay out the real pieces as planned, measuring every grainline to the selvage at both ends. Pin or weight, cut with long strokes, and cut notches outward.
7. Transfer all markings before removing the tissue. Label each piece on the wrong side with chalk.
8. **Conclude.** How close was your scale plan to the real yardage? Which width is the better buy for this garment?
9. **Repeat round.** Rearrange the scale pieces once more to beat your best efficiency by at least 3%.

Tips

- Lay the largest pieces first and fill gaps with small ones, the cutter's oldest rule.
- Weights (cans, washers) are faster than pins and do not distort the fabric.
- Keep the scale layouts; Unit 10's capstone will need one.

Check your work

- ☐ I planned two scaled layouts and calculated yardage and efficiency.
- ☐ I straightened the fabric and checked every grainline at both ends.
- ☐ I cut accurately and transferred every marking.

LAB NOTEBOOK

1. Draw and label every common pattern symbol.
2. Tape in your two scaled layouts with yardage and efficiency.
3. Write a step-by-step cutting checklist to keep with your sewing supplies.

KEY FORMULAS

$$\text{scale length} = \frac{\text{real length}}{8} \quad (1:8 \text{ scale})$$

$$\text{scale length} = 8 \text{real length} \quad (1:8 \text{ scale})$$

$$\text{fabric efficiency} = \frac{\text{total area of pieces}}{\text{area of fabric used}} \times 100\%$$

$$\text{fabric efficiency} = \text{area of fabric used} \div \text{total area of pieces} \times 100\%$$

From history. Nineteenth-century tailors' books such as those of the London and New York cutting schools taught "drafting systems," formulas for drawing a coat directly on cloth or paper from a few measurements. Many home dressmakers of the time also bought systems with adjustable rulers and charts, before printed graded patterns made drafting optional for most.

WORKED EXAMPLES

Example 1. A pant front is 13 in wide and 42 in long; a pant back is 15 in wide and 43 in long; two of each are needed. On 60-in fabric folded selvage to selvage (30 in wide doubled), one front and one back fit side by side across the fold. What length of fabric is needed, plus 4 in for a waistband cut crosswise?

Show solution

1. Side by side: $13 + 15 = 28 \text{ in} \leq 30 \text{ in}$, so both fit across, and cutting double gives two of each.
2. Length: the longer piece, 43 in, plus 4 in: $47 \text{ in} \approx 1.31 \text{ yd}$

Answer: About $1\frac{1}{3}$ yd of 60-in fabric; buy $1\frac{1}{2}$ yd to allow for straightening and shrinkage.

Example 2. On 45-in fabric folded ($22\frac{1}{2}$ in wide doubled), the front and back cannot fit side by side. Laid end to end, what length is needed? Compare with the 60-in layout.

Show solution

1. End to end: $42 + 43 + 4 = 89 \text{ in} \approx 2.47 \text{ yd}$
2. That is nearly twice the 60-in layout, though the width is only 25% less.

Answer: About $2\frac{1}{2}$ yd of 45-in fabric; buy $2\frac{5}{8}$ yd.

Example 3. The four pant pieces (two each of the sizes above) have a total area of $2(13 \times 42) + 2(15 \times 43) = 2,382 \text{ in}^2$. Find the efficiency of 47 in of 60-in fabric.

Show solution

1. Fabric area: $47 \times 60 = 2,820 \text{ in}^2$
2. Efficiency: $\frac{2,382}{2,820} \times 100\% = 84\%$, an upper bound, since the curved pieces actually use less than their rectangles.

Answer: At most about 84%; the real pieces leave curved scraps, so actual efficiency is somewhat lower.

PRACTICE

1. Easy What must the grainline arrow be parallel to?

Show answer

The selvage (lengthwise grain).

2. Easy What does the place-on-fold symbol mean?

Show answer

The piece's edge is laid exactly on the fold so it is cut as one double-width piece.

3. Easy What is nap, and give two napped fabrics.

Show answer

A one-way surface or design; corduroy, velvet (also flannel, one-way prints).

4. Medium At 1:8 scale, how long is a 44-in piece?

Show answer

$5\frac{1}{2}$ in.

5. Medium A grainline arrow measures 6 in from the selvage at one end and $6\frac{3}{8}$ in at the other. What must you do?

Show answer

Shift the piece until both ends measure the same before pinning.

6. **Medium** Why do garments cut off-grain twist after washing?

Show answer

Yarns relax back toward their true grain, pulling the seams and hems into a twist.

7. **Medium** Name three ways to transfer pattern markings.

Show answer

Tailor's chalk, tracing wheel and paper, tailor's tacks (also washable marker, snips at notches).

8. **Hard** A vest needs pieces totaling 1,150 in² laid in 27 in of 45-in fabric. Find the efficiency.

Show answer

$$1,150/1,215 \approx 94.7\% \quad 1,150/1,215 \approx 94.7\%$$

9. **Hard** Two pieces 16 in and 12 in wide must fit side by side on folded 45-in fabric. Do they?

Show answer

Folded width is 22½ in; 28 in does not fit, so they must be laid end to end (or the fabric opened single layer).

10. **Hard** Why might a skirt be cut on the bias deliberately?

Show answer

Bias drapes and stretches, giving a soft, flowing hang that molds to movement.

11. **Challenge** A print is printed 1 in off-grain across a 45-in width. Do you follow the print or the grain for a pair of pajama pants? Defend your choice.

Show answer

Follow the grain: the pants will hang straight and not twist in washing; a small print tilt is barely visible in a busy print, while twisted legs would show every day. (For a bold stripe or check, choose different fabric.)

COMMON MISTAKES

- Measuring the grainline at only one end. Measure both ends to the selvage.
- Cutting without checking that the fabric is on grain.
- Forgetting to transfer marks before unpinning the pattern.

Make it a game · Tetris on the Table. Cut paper pattern pieces at 1:8 scale for a simple garment. Each player gets the same pieces and a scaled rectangle of fabric. Race to lay out every piece on grain using the least length. The shortest valid layout wins; a parent checks grainlines, and any piece off-grain disqualifies the layout.

8.4 THE MUSLIN AND THE FITTING

OBJECTIVES

- Explain why sewers make a test garment (muslin or toile) and how to sew one quickly.
- Read fitting wrinkles and identify the adjustment each one calls for, described neutrally as fit.
- Make and record lengthen, shorten, widen and narrow adjustments, distributing changes across seams correctly.

Warm-up. Put on a garment that does not fit you comfortably and notice where it pulls or bunches. Which way do the wrinkles point? Write your guess of what each wrinkle is telling you.

WATCH

Mastering Garment Fitting: Muslin Demo and In-Depth Explanation

Susan Elias Couture • 11:19

<https://www.youtube.com/watch?v=heGZvRDYuz4>

WHEN TO WATCH

After “How they figured it out.” Watch the muslin pinned and marked on the dress form, and note how each change is recorded for the pattern.

KEY TERMS

muslin (toile)

A test garment sewn from inexpensive fabric to check fit before cutting the real fabric.

drag lines

Diagonal wrinkles that point toward a place where the garment is too tight or too short.

slash and spread

Cutting a pattern piece and spreading the pieces apart to add width or length, then redrawing smooth edges.

basting

Long temporary stitches, by hand or machine (4–5 mm), that hold a garment together for fitting and are easily removed.

lengthen/shorten line

A double line printed on a pattern where it can be cut and spread or folded to change length without distorting its shape.

true (a seam)

To redraw a seamline smoothly after an adjustment so matching seams are the same length.

CORE IDEAS

The story. In the great dressmaking houses of Paris, and in tailors' shops for centuries, a garment was fitted before it was finished. The tailor or dressmaker made it up loosely in a plain fabric, the customer tried it on, and the maker pinned and chalked every change. Mary Cassatt's print *The Fitting* (1890–91) shows that moment: a dressmaker kneeling to pin a hem while the customer watches in a mirror. Home sewers adopted the same habit with inexpensive unbleached cotton called muslin, and a muslin is still the professional's insurance against wasting good fabric.

How they figured it out. Fitters learned to read wrinkles as clues. Horizontal pull lines across a part of the body mean the garment is too tight there; vertical folds mean it is too loose; diagonal drag lines point toward the place that needs more room or length. A hem that dips or rides up shows a length problem in front or back. A side seam that swings forward or back shows a balance problem. Each wrinkle names an adjustment.

The fabric science. Fit changes happen at specific places on the pattern. Length is changed at the lengthen/shorten lines so that curves (the crotch, the armhole) keep their shape. Width is changed at seams, and a change in circumference is shared among all the seam edges that run around the body: a pair of pants with a front and back on each side has four side-seam edges (and the center seams), so adding 2 in of hip circumference at the side seams means ½ in on each edge. Every change must be *true*d: the matching seam on the next piece must be changed to the same length, and the cutting line redrawn smoothly.

Fit, not judgment. Every person's shape is different, and a pattern is drafted for an average that nobody exactly matches. Adjusting a pattern is simply fitting the garment to the real person, as every tailor has always done. Fitting remarks in this course name the

garment's problem ("the back waist pulls down when sitting; add back rise") and never comment on the body.

The studio lab. You will baste your muslin pajama pants from Lesson 8.3, try them on with a parent fitting (the father for a son or the mother for a daughter), check them standing, sitting, bending and stepping, mark changes, and transfer each change to the paper pattern, trued and labeled.

PICTURE STUDY



The Fitting, Mary Cassatt, 1890–91 · Drypoint · National Gallery of Art, Washington, D.C.

Image: [Wikimedia Commons](#), public domain

Mary Cassatt, an American working in Paris, made prints of women's daily life. In this drypoint a young woman stands for the fitting of a new dress while the dressmaker, seen from behind, kneels at her side, and the scene is reflected in a mirror. It is the oldest moment in dressmaking: the fitting.

Look closely

- Find the dressmaker. Where is she working, and what might she be pinning?
- Find the mirror. Why would a fitting room have one?
- Look at the lines of the dress. How does Cassatt show its folds with only a few strokes?
- Look at the customer's posture. Why would a fitter ask her to stand still and naturally?

Talk about it

1. Which fitting check from this lesson is the dressmaker making?
2. Why must a hem be pinned while the garment is being worn rather than laid flat?
3. What does the print suggest about the trust between a dressmaker and her customer?

Safety first. Fitting is done by a parent (the father for a son or the mother for a daughter), over light clothing or with the muslin worn over light clothing; pins are placed with their points facing away from the body and removed carefully before the muslin comes off. Comments name the garment's fit, never the body.

STUDIO LAB

Fit the Muslin, Fix the Pattern

Question: What adjustments does your pajama-pants pattern need, and can you transfer them accurately? You will baste and fit a muslin, mark changes, and true the paper pattern.

You will need

- The muslin pieces cut in Lesson 8.3, the paper pattern, the sewing machine
- Contrasting thread for basting, a 1-in elastic or a ribbon for a temporary waist
- Pins, a fabric marker, a mirror, extra pattern paper and tape, a ruler and French curve

Steps

1. **Hypothesis.** From your measurements and ease preference (Lesson 8.2), predict which adjustments you will need.
2. Machine-baste the muslin at a 4–5 mm stitch with $\frac{5}{8}$ -in seams: inseams, crotch seam, side seams. Pin the waist to a ribbon or elastic tied at the natural waist.
3. Mark the grainline and the hip line on the muslin with marker, so you can see whether they hang straight and level.
4. With your parent fitting, stand, sit, bend and step. Note every wrinkle and its direction. Pin out excess (vertical folds) or open seams and re-pin wider where it pulls.
5. Mark the new seamlines and the correct hem length with marker. Write each change on the muslin.
6. Take the muslin off carefully, remove pins, and measure each change.
7. Transfer each change to the paper pattern: fold or slash and spread at lengthen/shorten lines, add or remove at seam edges, and true every seam. Label the pattern “fitted” with the date.
8. **Conclude.** Which adjustments matched your prediction? Which surprised you?
9. **Repeat round.** Baste a second muslin leg from the adjusted pattern (or recut the muslin) and check it. Are the wrinkles gone?

Tips

- Fit one change at a time; changes interact.
- Photograph the fitting from front, side and back (dressed modestly, muslin over light clothing) to study wrinkles afterward.
- Keep the fitted muslin: it is a record of your shape for future patterns.

Check your work

- ☐ I basted a complete muslin and fitted it modestly with my parent.
- ☐ I identified each fit problem from its wrinkles and described it neutrally.
- ☐ I transferred, trued and labeled every change on the pattern and checked it.

LAB NOTEBOOK

1. Draw a wrinkle guide: horizontal pulls, vertical folds, drag lines, each with its meaning.
2. Record every adjustment with its measurement and where it was made.
3. Paste a photo or sketch of the trued pattern pieces.

KEY FORMULAS

$$\text{change per seam edge} = \frac{\text{total circumference change}}{\text{number of seam edges that share it}}$$

change per seam edge = number of seam edges that share ittotal circumference change

$$\text{new length} = \text{old length} \pm \text{adjustment at the lengthen/shorten line}$$

new length = old length $\pm$ adjustment at the lengthen/shorten line

From history. The French word toile (cloth) is the professional name for a muslin in tailoring and couture. Some tailoring houses keep a customer's fitted toile or paper pattern for decades and use it as the starting point for every new garment the customer orders.

WORKED EXAMPLES

Example 1. Muslin pants need 2 in more room at the hip. The change will be made at the side seams. How much is added to each pattern edge?

Show solution

1. Each side seam joins a front edge and a back edge, and there are two side seams: 4 edges.
2. $\frac{2 \text{ in}}{4} = \frac{1}{2} \text{ in}$ $42 \text{ in} = 21 \text{ in}$.

Answer: Add $\frac{1}{2}$ in at the hip on each front and back side-seam edge, tapering smoothly to the original line above and below.

Example 2. The pants are $1\frac{1}{2}$ in too long, and the pattern has lengthen/shorten lines on the front and back legs. How do you shorten them, and what else must change?

Show solution

1. Fold out a $\frac{3}{4}$ -in tuck ($1\frac{1}{2}$ in total length) along the line on each front and back leg piece.
2. Redraw (true) the inseam and side seam smoothly across the fold on each piece.
3. The front and back legs are now shortened by the same amount, so their seams still match.

Answer: Fold a $\frac{3}{4}$ -in tuck (which removes $1\frac{1}{2}$ in of length) on both front and back, and true the seams.

Example 3. A muslin's center-back seam pulls down when the wearer sits, and diagonal drag lines point toward the seat. What adjustment does this suggest, described as fit?

Show solution

1. Drag lines point toward the area that needs more room or length: the back crotch and seat.
2. Add back rise: slash the back pattern piece horizontally between the crotch and waist and spread it $\frac{1}{2}$ –1 in at center back, tapering to nothing at the side seam; true the curve.

Answer: More back rise (and possibly a slightly deeper back crotch curve). The garment needs the room; it says nothing else.

PRACTICE

1. Easy Why make a muslin?

Show answer

To test and adjust fit in inexpensive fabric before cutting the real fabric.

2. Easy What stitch length is used for machine basting?

Show answer

About 4–5 mm, the longest straight stitch.

3. Easy What do horizontal pull lines usually mean?

Show answer

The garment is too tight in that area.

4. Medium Add 3 in of waist room shared over 4 side-seam edges. How much per edge?

Show answer

$\frac{3}{4}$ in.

5. Medium Remove 1 in of hip room at 4 edges. How much per edge?

Show answer

$\frac{1}{4}$ in.

6. Medium Why are length changes made at the lengthen/shorten line rather than at the hem?

Show answer

To keep the shape of curves and the leg's taper; shortening at the hem changes the width at the hem and the proportions.

7. **Medium** What does truing a seam mean?

Show answer

Redrawing the seamline smoothly after an adjustment so matching seams are equal in length.

8. **Hard** A vest's front and back each have two side-seam edges. You must add 1½ in at the chest. How much per edge? What else must you check?

Show answer

¾ in per edge; true the armhole curve and side seams, and check the lining pieces get the same change.

9. **Hard** A hem rides up in front and dips in back. What does that suggest?

Show answer

The front needs more length (or the back less); a balance adjustment at the front waist or rise.

10. **Hard** Write a neutral fitting note for pants that are snug across the thighs when sitting.

Show answer

For example: "Thigh too snug when seated; add ½ in to each inseam edge at the thigh, tapering to the knee."

11. **Challenge** A sewer skips the muslin and cuts \$40 of wool directly. Using fabric cost, muslin cost (about \$4) and the odds of a fit problem, argue whether the muslin is worth it.

Show answer

If even a moderate chance of a fit problem would waste much of the \$40 (or force a poor-fitting garment), the \$4 and an evening are cheap insurance; and the corrected pattern can be reused for future garments, multiplying the value.

COMMON MISTAKES

- Fitting without the right undergarments and shoes for the finished garment. Wear what you will wear with it.
- Changing one edge of a seam and forgetting its partner. True both.
- Over-fitting. A garment needs ease; do not pin out the ease your preference requires.

Make it a game · Read the Wrinkle. A parent pins a muslin or an old garment on a chair-back or dress form in different wrong ways (too tight, too loose, too short in back) and players call out the problem and the fix. One point for the problem, one for the fix, and a bonus for using neutral words that name only the garment.

8.5 DRAFTING AND GRADING: HANNAH’S COAT EVERY YEAR

OBJECTIVES

- Draft a pajama-pants pattern from a well-fitting garment (the rub-off method) or from measurements, with seam and hem allowances and markings.
- Grade a pattern up or down a size by distributing grade amounts correctly.
- Calculate allowances, elastic length and grade distributions.

Warm-up. Read 1 Samuel 2:19. Hannah made Samuel “a little coat” and brought it every year. Why every year? What would she have needed to change each time?

WATCH

Drafting the Pajama Trousers (Easy Steps)Full Tutorial

Nice to Sew · 8:30

<https://www.youtube.com/watch?v=VbpFAEJmt2M>

WHEN TO WATCH

Watch with pattern paper, ruler and measurements ready. Pause after each line and draw it before moving on.

Note: A drafting method from measurements in centimeters; watch for the order of lines, then use your rub-off or your own measurements.

BACKUP VIDEO

Pattern Grading 101: How to Grade a Basic T-Shirt for Different Sizes

Pattern Studio 101 · 5:56

<https://www.youtube.com/watch?v=b6x9OH5VSbw>

A short explanation of grading: moving cut lines out or in by set amounts to make the next size.

KEY TERMS

drafting

Drawing a pattern from measurements or from an existing garment, rather than buying a printed one.

grading

Making a pattern in another size by moving its outlines out or in by set amounts at set places.

seam and hem allowances

The extra width added outside the stitching line ($\frac{5}{8}$ in for seams) and below the finished hem (often $1\frac{1}{4}$ –2 in).

rub-off

Copying a well-fitting garment's shape onto paper by tracing its seams and edges without taking it apart.

grade rule

The amount a pattern changes from one size to the next at a given point, such as 2 in of hip circumference per size.

crotch curve

The curved seam at the top of a pant leg piece, deeper in back than in front.

CORE IDEAS

The story. “Moreover his mother made him a little coat, and brought it to him from year to year, when she came up with her husband to offer the yearly sacrifice.” Hannah had given her son Samuel to serve the Lord at Shiloh, and every year she made him a new coat, each one larger than the last as he grew. She had no printed pattern; she would have judged his growth, enlarged the old shape and cut the new cloth by experience. That is drafting and grading, done by a mother's love, three thousand years before the Buttericks.

How they figured it out. The simplest pattern drafting copies something that already fits. Lay a favorite pair of pajama pants flat, fold one leg out of the way, and trace the other leg's front outline (side seam, hem, inseam, crotch curve, waist) onto paper; turn and trace the back the same way, easing out the deeper back crotch. Add seam allowances, a casing allowance at the waist and a hem allowance, and the pattern is done. Tailors' drafting systems do the same from measurements, using formulas to place each line.

Grading, by hand or computer, moves each point of the outline by a set amount for each size, following grade rules that keep the shape in proportion.

The fabric science (of pattern geometry). A pattern line is the stitching line plus an allowance. The waist of elastic-waist pants must be large enough to pull over the hips, so the pattern's waist equals the hip width plus ease, and the elastic gathers it in; elastic is usually cut a little shorter than the waist measurement (often about 2 to 4 in less) so it holds comfortably without squeezing. Grade amounts are shared among the pattern edges just like fit adjustments: a hip grade of 2 in per size spread over four quarter-panels (two fronts, two backs) moves each panel's side seam out $\frac{1}{2}$ in. Length grades are made at the lengthen/shorten line, and the crotch depth grades a little too.

Serving others. Grading is how a family's sewer makes the same pattern for every child. A pattern you draft and grade can make pajamas for a younger sibling this year and the next size next year, just as Hannah's little coats grew with Samuel.

The studio lab. You will rub off a well-fitting pair of pajama pants into a paper pattern (or adjust your fitted commercial pattern), add allowances and markings, then grade it to one size larger or smaller for a family member. This pattern carries straight into Unit 9.

PICTURE STUDY



The Infant Samuel Brought by Hannah to Eli, Gerbrand van den Eeckhout, 1665 · Oil on canvas · Ashmolean Museum, Oxford

Image: [Wikimedia Commons](#), public domain

Gerbrand van den Eeckhout, a pupil of Rembrandt, painted many Bible scenes. Here Hannah brings the young Samuel to the old priest Eli at Shiloh, keeping her promise to give her son to the Lord's service. From then on, Scripture says, she made him a little coat every year.

Look closely

- Find Hannah, Samuel and Eli. How does the painter show who is speaking and who is listening?
- Look at Samuel's clothing. How might it have been cut and sewn?
- Look at Eli's vestments. How does the painter show heavy cloth and folds?
- Find any gifts or offerings in the scene.

Talk about it

1. Imagine Hannah making the next year's coat. What would she need to know about Samuel to make it fit?
2. How is grading a pattern for a growing child an act of love and planning?
3. What does it mean that Scripture records something as ordinary as a yearly coat?

Safety first. Do not take apart a garment someone still wears without permission; the rub-off method traces it whole. Pins used to hold the garment while tracing go into the paper and table pad, never into skin, and are counted back into the pincushion. Use paper scissors for paper, never fabric shears.

Draft and Grade Your Pajama-Pants Pattern

Question: Can you draft a complete, accurate pajama-pants pattern from a garment that fits and grade it for someone else? You will rub off, add allowances and markings, test a corner, and grade one size.

You will need

- A pair of well-fitting woven pajama pants or elastic-waist pants
- Pattern paper at least 50 in long, a pencil, a clear ruler, a French curve, a tape measure, pins and a corkboard or padded table
- Your fitted muslin notes from Lesson 8.4 (if you used a commercial pattern)

RUB-OFF PAJAMA-PANTS PATTERN

Finished size: Two pattern pieces (front leg and back leg), each cut twice, plus a grade for one more size · About 2 hours

Fabric and notions

- One pair of well-fitting woven elastic-waist pants
- Pattern paper about 50 × 30 in (two sheets)
- Your measurement card and ease preference

How to make it

1. Turn the pants inside out and fold them in half so one front leg lies flat on top, the crotch seam pulled out flat. Pin through the seamlines into the paper.
2. Trace the front leg along the side seam, hem, inseam and front crotch curve, and across the top at the stretched-out waist. Mark the grain: a line parallel to the leg's center crease.
3. Repeat for the back leg, pulling the back crotch out fully; it will be deeper and longer than the front.
4. Remove the pants. True the traced lines with ruler and curve. These are stitching lines.
5. Add $\frac{5}{8}$ -in seam allowances on side seams, inseams and crotch, $2\frac{3}{4}$ in at the waist for the casing and 2 in at the hem. Draw notches at the hip and knee on both pieces so they match.
6. Label each piece: name, "cut 2," grainline, size, date. Check that front and back side seams and inseams are the same length.
7. Grade one size up or down on a copy, following worked example 2.

Fabric check: Trace from woven pants, not knits: a knit pattern has less ease and would make woven pants too tight. Flannel, cotton broadcloth or seersucker are good fabrics for the pants in Unit 9; avoid slippery satins for a first pair.

Steps

1. **Hypothesis.** Predict how much deeper the back crotch will be than the front, and how much larger the waist edge is than your waist.
2. Draft the pattern following the pattern card.
3. Measure and record: front and back crotch depth, waist edge, hip, inseam length. Check them against your measurement card plus your ease preference.
4. Cut one leg in muslin and baste the crotch and inseam to a mirror-image scrap, or compare carefully with your fitted muslin from Lesson 8.4.
5. Grade a copy for a family member's size and label it with their name and date.
6. **Conclude.** Did your drafted pattern match your fitted muslin? What would you change?
7. **Repeat round.** Correct any differences, re-true the seams and file the final pattern in a large envelope with its notes.

Tips

- Pin through the seams with the pin straight down; pins at an angle shift the line.
- A clean, true crotch curve is the heart of comfortable pants. Use a French curve or trace a dinner-plate edge.

- Write “fitted for [name], [date]” on the pattern: next year it will need grading, as Hannah's did.

Check your work

- ☐ I drafted front and back pattern pieces with correct allowances, grain and notches.
- ☐ My seams are trued and matching seams are the same length.
- ☐ I graded a second size for someone else correctly.

LAB NOTEBOOK

1. Draw your front and back pattern pieces small, labeling every line and allowance.
2. Write your grade rules and the per-edge amounts.
3. Copy 1 Samuel 2:19 and write who you will sew for next, and what you will make.

KEY FORMULAS

$$\text{cutting line} = \text{stitching line} + \text{allowance}$$

$$\text{cutting line} = \text{stitching line} + \text{allowance}$$

$$\text{grade per edge} = \frac{\text{grade per size}}{\text{number of edges}}$$

$$\text{grade per edge} = \text{number of edges} \times \text{grade per size}$$

$$\text{elastic length} \approx \text{waist measurement} - 2 \text{ to } 4 \text{ in} + 1 \text{ in overlap}$$

$$\text{elastic length} \approx \text{waist measurement} - 2 \text{ to } 4 \text{ in} + 1 \text{ in overlap}$$

From history. Today most pattern grading is done by computer, with grade rules stored for every point of a pattern. But the logic is unchanged since the Buttericks: move each point by a set amount per size, and keep the proportions.

WORKED EXAMPLES

Example 1. Your traced pant front leg measures 41 in from the waist stitching line to the hem fold. You want a casing $1\frac{1}{4}$ in wide for 1-in elastic (casing allowance = $2 \times 1\frac{1}{4} + \frac{1}{4}$ in turn-under) and a $1\frac{1}{2}$ -in hem plus $\frac{1}{2}$ in turn-under. What is the total cut length?

Show solution

1. Casing allowance: $2 \times 1.25 + 0.25 = 2.75$ in $2 \times 1.25 + 0.25 = 2.75$ in.
2. Hem allowance: $1.5 + 0.5 = 2.0$ in $1.5 + 0.5 = 2.0$ in.
3. Cut length: $41 + 2.75 + 2.0 = 45.75$ in $41 + 2.75 + 2.0 = 45.75$ in.

Answer: 45¾ in from top cutting line to bottom cutting line.

Example 2. A pajama-pants pattern grades 2 in of hip per size, shared by two fronts and two backs at the side seams, and 1 in of length per size at the lengthen/shorten line. How do you grade one size up?

Show solution

1. Width: $2 \text{ in} \div 4 = \frac{1}{2} \text{ in}$ $2 \text{ in} \div 4 = \frac{1}{2} \text{ in}$, moved outward at each side seam, tapering to about $\frac{3}{8}$ in at the hem if the leg is tapered.
2. Length: spread each front and back leg 1 in at the lengthen/shorten line and true the seams.

Answer: Move each side seam out $\frac{1}{2}$ in and add 1 in of length; true all seams and the waist.

Example 3. The waist measures 30 in. Using elastic 3 in shorter than the waist plus 1 in to overlap and stitch, how long do you cut the elastic? How long must the casing opening around the waist be if the hips measure 40 in with 4 in of ease?

Show solution

1. Elastic: $30 - 3 + 1 = 28$ in $30 - 3 + 1 = 28$ in.
2. Casing (waist edge of the pants): at least $40 + 4 = 44$ in $40 + 4 = 44$ in, so it pulls over the hips.

Answer: Cut 28 in of elastic; the waist edge must be at least 44 in around.

PRACTICE

1. **Easy** Quote 1 Samuel 2:19's first clause.
Show answer
Moreover his mother made him a little coat.
2. **Easy** What is a rub-off?
Show answer
Copying a well-fitting garment's shape onto paper without taking it apart.
3. **Easy** What is the standard seam allowance on commercial patterns?
Show answer
 $\frac{5}{8}$ in.
4. **Medium** A stitching line is 38 in; add a $\frac{5}{8}$ -in allowance at both ends. Cut length?
Show answer
 $39\frac{1}{4}$ in.
5. **Medium** Grade $1\frac{1}{2}$ in of waist per size across 4 edges. How much per edge?
Show answer
 $\frac{3}{8}$ in.
6. **Medium** Elastic for a 26-in waist using "2 in shorter plus 1 in overlap"?
Show answer
25 in.
7. **Medium** Why is the back crotch curve deeper than the front?
Show answer
The seat needs more room and length for sitting and bending.
8. **Hard** Grade a pattern two sizes down at 2 in of hip per size, 4 edges. How far does each side seam move, and which way?
Show answer
 $4 \text{ in} \div 4 = 1 \text{ in}$ $4 \text{ in} \div 4 = 1 \text{ in}$ inward at each edge.
9. **Hard** Pants with a 1-in elastic need a casing of elastic width + $\frac{1}{4}$ in, folded double plus a $\frac{1}{4}$ -in turn-under. Find the casing allowance.
Show answer
 $2 \times 1.25 + 0.25 = 2.75 \text{ in}$ $2 \times 1.25 + 0.25 = 2.75 \text{ in}$
10. **Hard** Why must the waist edge of pull-on pants be at least the hip measurement plus ease?
Show answer
The pants must pull up over the hips; the elastic then gathers the larger waist edge in.
11. **Challenge** A child grows about 2 in taller and 1 in larger at the hip each year. Plan how Hannah-style yearly pajamas could be graded from one pattern for three years, and the total length and width added.
Show answer
Each year add about $1\frac{1}{2}$ –2 in of leg length at the lengthen/shorten line (and a little rise) and $\frac{1}{4}$ in at each of 4 side-seam edges (1 in hip); over three years about 5–6 in of length and 3 in of hip, with seams trued each time and the elastic recut.

COMMON MISTAKES

- Tracing the waist where it is gathered by elastic. Stretch the waist flat to trace its full width.
- Forgetting the back crotch is deeper. Copy the real curves, front and back.
- Grading at only one seam. Share the grade across all edges so the shape stays balanced.

Make it a game · Grade It in Your Head. A parent calls a grade problem: “Hip grade 2 inches, four edges, two sizes up: how far does each side seam move?” First correct answer scores a point. Mix in elastic lengths and allowance sums. After ten rounds, the winner chooses the fabric for the pajama pants in Unit 9.

Scripture. “Moreover his mother made him a little coat, and brought it to him from year to year, when she came up with her husband to offer the yearly sacrifice.” (1 Samuel 2:19, KJV)

A mother's yearly coat for a growing boy is the oldest picture of drafting and grading. Sewing for those we love, and changing the pattern as they grow, is faithful work.

UNIT 8 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (7 pts)
Tell the story of the Butterick graded pattern in three sentences.
2. (7 pts)
List six items on a pattern envelope and say how you choose a size.
3. (7 pts)
A shirt needs $2\frac{1}{8}$ yd of 45-in at \$8.49 or $1\frac{5}{8}$ yd of 60-in at \$11.99. Which is cheaper and by how much?
4. (7 pts)
Describe how measurements are taken in this course and how they are treated.
5. (7 pts)
A garment laid flat measures 23 in across the hip; the body hip is 41 in. Find the ease and say whether it is wearing or design ease.
6. (7 pts)
Define wearing ease, design ease and negative ease, with a garment for each.
7. (7 pts)
Explain how to check and correct grain before cutting, and why it matters.
8. (7 pts)
Two pant pieces 14 in and 16 in wide: do they fit side by side on folded 60-in fabric? On folded 45-in? Explain.
9. (7 pts)
A layout uses 52 in of 60-in fabric for pieces totaling 2,600 in². Find the efficiency.
10. (6 pts)
What do horizontal pull lines, vertical folds and diagonal drag lines each tell a fitter?
11. (7 pts)
Add $2\frac{1}{2}$ in of hip room at four side-seam edges and shorten pants 1 in. Describe both changes on the pattern.
12. (6 pts)
A leg stitching length of 40 in needs a $2\frac{3}{4}$ -in casing allowance and a 2-in hem allowance. Find the cut length.
13. (6 pts)
Grade one size up: hip grade 2 in over 4 edges, length grade $1\frac{1}{4}$ in. Describe the changes.
14. (6 pts)
Elastic for a 28-in waist, cut 3 in shorter plus 1 in overlap? Why must the waist edge exceed the hip?
15. (6 pts)
Short essay (5–7 sentences): Using Hannah's coat (1 Samuel 2:19), the Buttericks and your own lab, explain why drafting, fitting and grading are acts of care as well as skill.

UNIT PROJECT: A FITTED MUSLIN AND A PERSONAL PATTERN

Present your fitted muslin pajama pants and your final paper pattern: front and back pieces with allowances, grainlines, notches, labels and the date, plus one graded size for a family member.

Include your measurement card (kept private, shown only to your parent), your ease table, your scale layouts with yardage and efficiency, your fitting notes with each adjustment, and a one-page reflection on what you learned about fit.

LOOK FOR	WHAT IT MEANS
Modest, accurate measuring	Measurements were taken properly by a parent, recorded privately and used for fit only.
Pattern accuracy	Pieces have correct allowances, grainlines and notches, with trued seams of matching length.
Fitting	The muslin shows each adjustment marked and transferred, and fitting notes describe the garment neutrally.
Calculations	Yardage, efficiency, ease, adjustment and grading calculations are correct with units.
Service and records	A graded size is prepared for someone else, and all records are complete and dated.

ANSWER KEY

1. In 1863 the tailor Ebenezer Butterick and his wife Ellen, of Sterling, Massachusetts, began selling tissue-paper patterns graded in sizes, first for men's and boys' clothes. They moved to New York and built a large company, selling millions of patterns and publishing The Delineator. Graded patterns let home sewers cut accurate garments in many sizes.
2. Views, description, size chart, finished measurements, yardage chart, notions, suggested fabrics (any six). Choose by body measurements on the size chart, not by store size.
3. 45-in \$18.04; 60-in \$19.48; the 45-in by \$1.44.
4. Over light clothing, by a parent (father for son, mother for daughter for older students), tape snug and level, recorded privately and dated, used for fit only, never judged or compared.
5. $46 - 41 = 5$ in $46 - 41 = 5$ in: wearing ease plus some design ease for a relaxed fit.
6. Wearing: room to move (a woven shirt). Design: added style fullness (pajama pants, a smock). Negative: smaller than the body, only in stretch knits (socks, rib cuffs).
7. Tear or pull a thread across, fold selvage to selvage and see if ends meet squarely; pull diagonally to correct. Measure each grainline arrow to the selvage at both ends. Off-grain garments twist and hang badly after washing.
8. 60-in folded is 30 in: yes (30 in exactly). 45-in folded is $22\frac{1}{2}$ in: no; lay end to end.
9. $2,600/3,120 \approx 83\%$ $2,600/3,120 \approx 83\%$
10. Horizontal pulls: too tight there. Vertical folds: too loose. Drag lines: point toward an area needing more room or length.
11. Add $\frac{5}{8}$ in to each front and back side-seam edge at the hip, tapering; fold a $\frac{1}{2}$ -in tuck (1 in total) at the lengthen/shorten line on front and back legs; true all seams.
12. $44\frac{3}{4}$ in.
13. Each side seam out $\frac{1}{2}$ in; spread $1\frac{1}{4}$ in at the lengthen/shorten line on front and back; true seams.
14. 26 in. The pants must pull over the hips; elastic gathers the larger edge.
15. A strong essay connects Hannah's yearly coat to grading for growth, the Buttericks' help to families sewing for many sizes, respectful measuring and neutral fitting, and the student's own pattern made for someone else.

GARMENT CONSTRUCTION

This is the unit where everything comes together into clothes you wear. You will learn the techniques that turn flat pieces into a garment: darts that make cloth curve, casings and elastic for pull-on waists, zippers from Whitcomb Judson's clasp locker to Gideon Sundback's hookless fastener, facings and collars that finish an edge cleanly, set-in sleeves, buttonholes, buttons and hems, and the order of construction that makes each step easier than the last.

Two garments carry the unit. First, a pair of pajama pants from the pattern you drafted and fitted in Unit 8, with a proper casing, finished seams and a neat hem. Second, a lined vest (or, for experienced sewers, a button-front shirt), interfaced, faced or bagged, with machine buttonholes and sewn-on buttons. Samplers come first in each lesson so that your real garments get your best work, and every lesson keeps the machine rules: fingers clear, pins pulled, machine unplugged for needle changes.

PREREQUISITES

- Unit 7: machine skills, seams, finishes and pressing, signed off by a parent
- Unit 8: your fitted pajama-pants pattern and measurement card
- A vest pattern (commercial or drafted) and about 1¼ yd each of shell fabric and lining, plus interfacing and buttons

MASTERY CHECKLIST

- ☐ I can mark, sew and press a dart and explain how darts shape flat cloth.
- ☐ I can sew a casing, insert and join elastic, and calculate elastic length.
- ☐ I can insert centered and lapped zippers and tell the history of the zipper.
- ☐ I can apply interfacing and facings, understitch, clip and notch curves, and explain how collars and set-in sleeves are eased.
- ☐ I can space and sew machine and hand-worked buttonholes and buttons with shanks, and choose and sew a hem.
- ☐ I can plan the order of construction and complete a pair of pajama pants and a lined vest or shirt.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **A buttonhole foot and a zipper foot:** Most machines come with both; check the accessory box. They make Lessons 9.3 and 9.5 far easier.
- **Fusible interfacing (lightweight woven or nonwoven):** About ½ yd for vest facings or a shirt collar and cuffs; choose a weight a little lighter than the fashion fabric.
- **A point turner and a loop turner:** Inexpensive tools for crisp collar points and for turning narrow ties; a chopstick works for points.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

9.1	Darts: Making Flat Cloth Round	3 sessions of 50–90 minutes
9.2	Casings, Elastic and Pajama Pants	3 sessions of 60–90 minutes
9.3	Judson, Sundback and the Zipper	3 sessions of 50–90 minutes
9.4	Facings, Collars and Sleeves	3 sessions of 60–90 minutes
9.5	Buttonholes, Buttons and Hems	3 sessions of 60–90 minutes

9.1 DARTS: MAKING FLAT CLOTH ROUND

OBJECTIVES

- Explain how darts, seams and shaped panels turn flat cloth into curved shapes, and tell how fitted tailoring began.
- Mark, sew, tie off and press straight, curved and double-ended darts.
- Calculate dart intake and use geometry to shape a fabric basket with corner darts.

Warm-up. Lay a sheet of paper flat on a mixing bowl turned upside down. Try to make it fit the bowl smoothly. Now fold small wedges at the edges and tape them. What did the folds do?

WATCH

How to Sew a Dart

[Threads Sewing](#) · 3:43

<https://www.youtube.com/watch?v=tLwlwcmAu4c>

WHEN TO WATCH

Watch once, then again with your marked sampler at the machine, pausing before you sew each dart.

BACKUP VIDEO

How to Sew Darts for Garment Sewing and Contour

[Professor Pincushion](#) · 3:53

<https://www.youtube.com/watch?v=6a1g3MhLp2M>

A second teacher's method for a smooth dart point, for comparison.

KEY TERMS

dart

A stitched, tapered fold that removes a wedge of fabric so flat cloth curves over a shape.

intake

The width of fabric a dart removes at its widest point.

shaped panel

A tapered panel of a skirt or garment, narrower at the top, that shapes by seams instead of darts.

dart legs and point

The two stitching lines of a dart (equal in length) and the place where they meet and vanish.

double-ended (fisheye) dart

A dart pointed at both ends and widest in the middle, used to shape a waist in a one-piece garment.

tie off

Knotting the thread ends at a dart point instead of backstitching, so the point lies flat.

CORE IDEAS

The story. For most of history clothing was made of rectangles and triangles: tunics, gowns and cloaks cut straight from the loom and belted. In the 1300s, European tailors began cutting cloth into curved, shaped pieces that followed the body, with seams and shaping that let a garment fit closely and still move. Historians often mark that change as the beginning of tailoring as a separate craft, and darts, shaped panels and curved seams became the tailor's basic tools for turning a flat length of cloth into something that fits a rounded person.

How they figured it out. Cloth is flat and people are not. A flat sheet laid over a dome must either stretch, wrinkle or lose some of its edge. A dart is a deliberate loss: it folds out a wedge, so the edge becomes shorter while the middle stays full, and the cloth becomes a shallow cone. Several small darts shape more smoothly than one big one, and moving dart width into seams (as long curved panel seams do) gives the same shape without darts at all. Shaped panels do the same in skirts: narrow at the waist, wide at the hem.

The fabric science. Geometry explains it. If you cut a wedge of angle θ out of a flat circle and join the edges, you get a cone, and the circumference at any radius shrinks by the arc you removed. A waist dart with a 1-in intake makes the waist edge 1 in shorter while the fabric below it keeps its width: shaped room for the curve. Dart legs must be exactly equal in length, or one side of the garment

will be longer than the other. The point must taper gradually to the fold, ending with the last two or three stitches right on the fold edge, or the dart will pucker into a bubble at its tip. Pressing over a ham finishes the shape.

Sewing a good dart. Mark the legs and point accurately (tracing wheel or chalk), fold through the center with the legs matching, pin, and sew from the wide end toward the point, tapering so the last stitches run off the fold. Do not backstitch at the point; leave long thread tails and tie them in a square knot. Press the dart flat as sewn, then over a ham toward the center or downward, as the pattern directs.

The studio lab. You will sew a dart sampler (straight, curved and double-ended darts), measure intake and shape, then put darts to work in a useful object: a fabric storage basket for your sewing tools, shaped by four corner darts whose depth you calculate.

PICTURE STUDY



The Little Seamstress (Die kleine Näherin), Albert Anker, 1908 · Watercolor · Image from Wikimedia Commons, public domain
Image: [Wikimedia Commons](#), public domain

Albert Anker painted the children and grandparents of the Swiss village of Ins with great tenderness. Here a girl sits absorbed in her sewing. Children in his day learned to sew young, mending and making garments for the family.

Look closely

- Find her needle and thread. How is she holding the cloth?
- Look at the garment or cloth in her lap. Is it flat, or already shaped?
- Find any sewing tools or a workbasket nearby.
- Look at the light on her face and hands. Where is it coming from?

Talk about it

1. Sewing by hand, how would she make a garment fit a rounded shoulder or waist?
2. What skills would she need before she could sew a dart neatly by hand?
3. Why might Anker paint children at work so often and so respectfully?

Safety first. Keep fingers an inch from the needle and slow down as you approach the dart point. Use a tracing wheel on a protected table surface, and keep chalk dust off food areas. Press with the iron upright between uses and unplug it when you finish.

STUDIO LAB

A Dart Sampler and a Sewing-Tool Basket

Question: How exactly do dart intake and position change a flat piece into a shape? You will sew a dart sampler, then make a lined fabric basket for your sewing tools shaped by four corner darts.

You will need

- Muslin scraps for the sampler, a tracing wheel and paper or chalk
- Two 14 × 14 in squares: one sturdy cotton (canvas, denim or home-décor weight) and one cotton lining; a 13 × 13 in square of fusible interfacing
- Matching thread, the iron, a tailor's ham or rolled towel

CORNER-DARTED FABRIC BASKET

Finished size: One lined basket about 7 × 7 in at the base and 3 in deep · About 90 minutes

Fabric and notions

- One 14 × 14 in square of sturdy cotton for the outside
- One 14 × 14 in square of cotton for the lining
- One 13 × 13 in square of medium fusible interfacing
- Thread to match

How to make it

1. Fuse the interfacing to the wrong side of the outer square, centered, following the maker's directions with a press cloth.
2. On the wrong side of each square, mark a corner dart at all four corners: fold the corner diagonally and draw a line 3 in long, perpendicular to the fold, ½ in in from the raw edges (this boxes a 3-in-deep corner).
3. Sew each outer corner dart along the marked line, backstitching at both ends (these are boxing seams, not pointed darts). Trim to ¼ in. Repeat on the lining.
4. Press the outer basket over a ham. Turn the lining wrong side out and set it inside the outer basket, wrong sides together, corners matching.
5. Fold the top raw edges of both layers ½ in toward each other, pin, and edgestitch all around the top through all layers. (Or fold a 1½-in cuff down over the top for a softer look.)
6. Press the finished basket and fill it with your pins, snips and thread.

Fabric check: A firm cotton canvas, duck, denim or decorator cotton holds the shape best; quilting cotton needs heavier interfacing. Prewash both fabrics so the lining and outside shrink together. Old jeans make excellent baskets.

Steps

1. **Hypothesis.** Predict how much the edge of a 12-in muslin square shortens with one 1-in dart, and the base size of your basket.
2. **Sampler.** On muslin, mark and sew a straight dart (1 in intake, 4 in long), a curved dart and a double-ended dart. Tie off the points. Press each over the ham.
3. Measure each dart's intake and leg lengths, and the edge length before and after. Record.
4. Hold the sampler up to the light and inspect each point: does it vanish smoothly, or bubble? Re-sew any bubbly point.
5. **Basket.** Make the basket following the pattern card.
6. Measure the finished base and walls and compare with your calculation.
7. **Conclude.** How close was the geometry to the real result? What did the boxed corner and the pointed dart each do?
8. **Repeat round.** Make a second basket with 2-in or 4-in corners for a different use (or as a gift) and predict its size first.

Tips

- Slow down for the last inch of a dart; stitch the final two or three stitches right on the fold.
- Leave 4-in thread tails at dart points so they are easy to tie.
- Pressing darts over a ham, not flat, is what makes them look professional.

Check your work

- ☐ I sewed three kinds of darts with equal legs and smooth points.
- ☐ I calculated and measured how darts changed shape and size.

- ☐ I made a sturdy, useful basket within ¼ in of its planned size.

LAB NOTEBOOK

1. Draw a dart on a pattern piece with legs, point, intake and fold line labeled.
2. Draw a flat circle with a wedge removed and the cone it makes, labeling the arc removed.
3. Tape in your dart sampler with measurements.

KEY FORMULAS

$$\text{new edge length} = \text{original edge length} - \sum \text{dart intakes}$$
$$\text{new edge length} = \text{original edge length} - \sum \text{dart intakes}$$

$$\text{arc removed} = \frac{\theta}{360^\circ} \times 2\pi r$$

$$\text{arc removed} = 360^\circ \cdot \theta \times 2\pi r$$

From history. Before tailors shaped garments with darts and curved seams, people fit loose clothing with belts, lacing and gathering. Many traditional garments around the world, such as the Japanese kimono and many shepherds' and peasants' tunics, are still cut almost entirely from rectangles to waste no cloth.

WORKED EXAMPLES

Example 1. A skirt front's waist edge measures 18 in between side-seam lines. The finished front waist should be 15 in. If you use two equal darts, what is each dart's intake?

Show solution

1. Total intake: $18 - 15 = 3$ in $18 - 15 = 3$ in.
2. Each dart: $3 \div 2 = 1.5$ in $3 \div 2 = 1.5$ in.

Answer: Two darts of 1½ in each.

Example 2. A circle of fabric 20 in in diameter has a 30° wedge removed and the edges joined into a shallow cone. How much shorter is the outer edge?

Show solution

1. Original circumference: $2\pi \times 10 = 62.8$ in $2\pi \times 10 = 62.8$ in.
2. Arc removed: $\frac{30}{360} \times 62.8 = 5.2$ in $\frac{30}{360} \times 62.8 = 5.2$ in.

Answer: The edge is about 5.2 in shorter, now 57.6 in: the cone's dart removed it.

Example 3. A fabric basket is cut from a 14 × 14 in square (after seam allowances, a 13 × 13 in finished square). Each corner gets a dart that boxes the corner 3 in deep. What are the finished base size and wall height?

Show solution

1. Each side loses the corner on both ends: base side $13 - 2 \times 3 = 7$ in $13 - 2 \times 3 = 7$ in.
2. Walls rise 3 in from each base edge (the boxed corner depth).

Answer: A basket about 7 × 7 in at the base with walls 3 in high.

PRACTICE

1. Easy What does a dart do to flat cloth?

Show answer

It removes a wedge so the edge shortens and the cloth curves into a shallow cone.

2. **Easy** Why tie off a dart point instead of backstitching?

Show answer

Backstitching at the point builds bulk and can pucker; tied threads let the point lie flat.

3. **Easy** What is a double-ended dart?

Show answer

A dart pointed at both ends and widest in the middle, shaping the waist of a one-piece garment.

4. **Medium** A waist edge of 16 in must finish at 13 in with three equal darts. Intake of each?

Show answer

1 in.

5. **Medium** Why must the two legs of a dart be exactly the same length?

Show answer

So the seam lines on both sides of the dart match; otherwise one side of the garment is longer and the edge is uneven.

6. **Medium** How does a shaped panel shape a skirt without darts?

Show answer

Each panel is narrower at the waist and wider at the hem, so the seams themselves remove width at the waist.

7. **Medium** Find the arc removed from a 16-in circle by a 45° wedge.

Show answer

$$\frac{45}{360} \times \pi \times 16 \approx 6.3 \text{ in}$$
$$\frac{45}{360} \times \pi \times 16 \approx 6.3 \text{ in}$$

8. **Hard** A basket from a 15-in finished square with 3½-in boxed corners: base size and wall height?

Show answer

Base 8 × 8 in; walls 3½ in.

9. **Hard** Why do several small darts give a smoother shape than one large dart of the same total intake?

Show answer

Each small dart shapes a smaller area gradually, spreading the curve and avoiding a sharp, bubbly point.

10. **Hard** A dart puckers at the point. List two likely causes and fixes.

Show answer

Not tapering to the fold (re-stitch so the last stitches run off the fold); backstitching at the point (unpick, re-sew and tie off); pressing flat instead of over a ham.

11. **Challenge** Explain why a flat map of the round earth must either stretch shapes or cut gaps, and connect it to darts.

Show answer

A sphere's surface cannot be flattened without distortion; maps stretch areas or split the globe into tapered segments. Fabric does the reverse: darts and gores remove the extra flat material so cloth can follow a curved surface.

COMMON MISTAKES

- Sewing straight off the dart point at an angle, leaving a bubble. Taper onto the fold.
- Marking dart legs inaccurately. Use a tracing wheel or chalk and a ruler.
- Pressing darts on a flat board, which flattens the shape they were sewn to make.

Make it a game · Bowl Challenge. Give each player a 12-in square of paper and tape. Race to make it fit a bowl turned upside down as smoothly as possible using only folded darts, no cuts. Then count the darts. The smoothest fit wins, and the player who used the fewest darts for a smooth fit wins a bonus.

9.2 CASINGS, ELASTIC AND PAJAMA PANTS

OBJECTIVES

- Tell the history of elastic from Thomas Hancock's rubber fastenings to modern covered elastics.
- Sew a casing, insert and join elastic so it does not twist, and finish seams and hems on a real garment.
- Plan the order of construction and calculate elastic length, yardage and garment cost.

Warm-up. Look at three elastic waistbands in the house (pajamas, sweatpants, a skirt). Stretch each. Is the elastic in a channel (casing), or sewn directly to the fabric? Does any of it twist or roll?

WATCH

Teach Yourself to Sew: How to Sew Casings for Elastic & Drawstrings

[Threads Sewing](#) · 4:51

<https://www.youtube.com/watch?v=Xi1NloETZnA>

WHEN TO WATCH

Watch with your pants and elastic ready; pause after each fold and press, then do it yourself.

BACKUP VIDEO

How to Sew an Elastic Waistband | How to Make a Casing

[The Awl-Nighter](#) · 4:20

<https://www.youtube.com/watch?v=Yqz2E-3TC8Y>

A second method for a casing that keeps the elastic from twisting.

KEY TERMS

casing

A channel of fabric, usually a folded edge, through which elastic or a drawstring is threaded.

order of construction

The sequence in which a garment's seams and details are sewn, planned so each step is easy and every seam can be pressed and finished.

stitch in the ditch

Stitching exactly in the groove of a seam on the right side, to hold layers (such as elastic in a casing) invisibly.

braided, knitted and woven elastic

Braided elastic narrows when stretched and suits casings; knitted is soft and stays the same width; woven (non-roll) is firm and resists rolling.

crotch seam

The curved seam joining the left and right halves of pants at center front and center back.

double-fold hem

A hem folded up twice so the raw edge is enclosed, then stitched.

CORE IDEAS

The story. Before elastic, clothing was held up by laces, buttons, ties and suspenders. In 1820 the English inventor Thomas Hancock patented elastic fastenings for gloves, shoes and stockings, cut from natural rubber; his machine for kneading scrap rubber into a usable mass helped found the rubber industry. Rubber turned sticky in heat and brittle in cold until vulcanization, discovered by Charles Goodyear in the United States in 1839 (patented 1844) and developed by Hancock in England, made it stable. Covered rubber thread, wrapped in cotton, made elastic waistbands possible, and spandex (Unit 3) later improved them. A pair of comfortable elastic-waist pajama pants is the fruit of a century of chemistry.

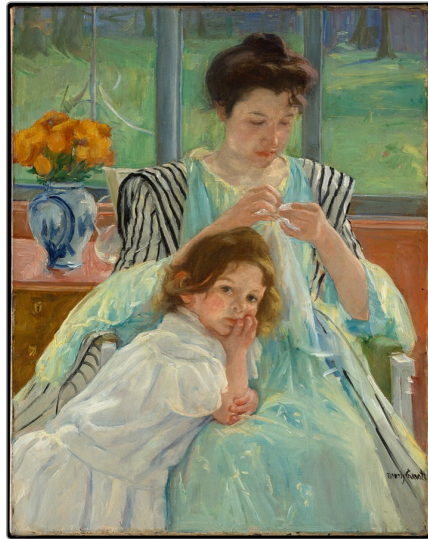
How they figured it out. Sewers learned that elastic works best in a channel slightly wider than itself, so it can move and gather the fabric evenly. Elastic that is too long sags; too short, it pinches. The usual rule is to cut it a few inches shorter than the waist measurement, overlap the ends and zigzag them flat, then distribute the gathers evenly and stitch through the casing at each side seam (or in the ditch) so it cannot twist in the wash.

The fabric science (of construction order). A garment goes together most easily when you sew the seams that will be crossed by other seams first, press each one before crossing it, and finish edges while you can still reach them flat. For pajama pants: (1) finish and sew the inseams of each leg; (2) turn one leg right side out, slip it inside the other, and sew the crotch seam in one continuous curve, reinforcing it with a second row of stitching; (3) press and finish; (4) fold and stitch the waist casing, leaving an opening; (5) insert, join and secure the elastic; (6) hem the legs. Each step's seam finish should match your Unit 7 choice for the fabric.

Curves. The crotch seam is curved and takes great strain in sitting and bending. Sew it twice (a second row $\frac{1}{8}$ in into the allowance), trim the curve below the second row, and finish the edges together; clipping weakens it, so curves in pants are reinforced rather than clipped deeply.

The studio lab. You will sew your fitted pajama pants from the Unit 8 pattern, start to finish, keeping a construction log of each step, time and any unpicking, and calculating the true cost of the garment.

PICTURE STUDY



Young Mother Sewing, Mary Cassatt, 1900 · Oil on canvas · The Metropolitan Museum of Art, New York

Image: [Wikimedia Commons](#), public domain

Mary Cassatt painted mothers and children throughout her career. Here a young mother sews in a sunlit room while a little girl leans against her knee and looks out at us. The sewing is ordinary family work: clothes made and mended for the household at home.

Look closely

- Find the needle and the garment in her hands. What might she be making?
- Look at the child. How does she show that she is part of the scene?
- Find the window and the light. How does Cassatt paint the white fabric?
- Look at the brushstrokes in the dress and background. How finished is the painting?

Talk about it

1. What kinds of garments would a mother in 1900 have sewn for her children at home?
2. How does this painting show sewing as an act of love and care?
3. If the little girl were learning to sew, what would you teach her first?

Safety first. Keep fingers an inch from the needle, pull pins before the presser foot, and slow down on curves. When inserting elastic with a safety pin, keep the pin closed and count it back to the pincushion. Press each seam with the iron set for the fabric and unplug it when you finish.

Sew Your Fitted Pajama Pants

Question: Can you build a complete garment from your own pattern, in a sensible order, with finished seams and a secure casing? You will sew, log and cost your pajama pants.

You will need

- Your fitted pajama-pants pattern from Unit 8
- Woven cotton flannel, broadcloth or seersucker, yardage from your Unit 8 layout, prewashed
- 1-in braided or knitted elastic, matching thread, a large safety pin or bodkin
- Pins, the iron, your seam-finish choice from Unit 7

ELASTIC-WAIST PAJAMA PANTS

Finished size: One pair, fitted to the wearer · About 4–6 hours over two or three sessions

Fabric and notions

- 2–3 yd of 45-in woven cotton (from your layout), prewashed and pressed
- Elastic: waist measurement minus 2–4 in, plus 1 in overlap
- One spool of all-purpose thread to match

How to make it

1. Cut two fronts and two backs on grain, mirror-imaged; transfer notches. Label fronts and backs.
2. Sew each leg's inseam (front to back) right sides together at $\frac{5}{8}$ in; finish and press toward the back.
3. Turn one leg right side out and slip it inside the other (right sides together). Match inseams and notches and sew the crotch seam in one curve; sew a second row $\frac{1}{8}$ in inside it; trim and finish.
4. Sew the side seams if your pattern has them; finish and press.
5. Fold the waist edge $\frac{1}{4}$ in, then the casing depth; press. Stitch close to the lower fold, leaving a 2-in opening at the back seam.
6. Thread the elastic through with the safety pin, keeping it flat. Overlap the ends 1 in and zigzag them together. Close the opening, distribute gathers, and stitch in the ditch at each side seam.
7. Try on, mark the hem, and sew a double-fold hem ($\frac{1}{2}$ in then $1\frac{1}{2}$ in). Press the finished pants.

Fabric check: Flannel, broadcloth, chambray and seersucker are easy to sew and comfortable. Prewash everything; cotton flannel can shrink 5% or more. Avoid slippery satins and stretchy knits for a first pair. Directional prints must have all pieces pointing the same way.

Steps

1. **Hypothesis.** Estimate your total sewing time and cost before you start.
2. Sew the pants following the pattern card. Press every seam before crossing it.
3. Keep a construction log: each step, the time it took, and anything you unpicked and why.
4. Try the pants on before hemming: sit, bend and step. Note the fit compared with the muslin.
5. Calculate the true cost of the garment from your receipts and the thread used.
6. **Conclude.** Which step took longest? What would you do differently on the next pair?
7. **Repeat round (or service round).** Sew a second pair from your graded pattern for the family member you graded it for in Lesson 8.5, using your log to work faster.

Tips

- Mark the back with a small safety pin or a tag; front and back look alike once sewn.
- A wider casing than the elastic by $\frac{1}{4}$ in lets it slide; more than $\frac{1}{2}$ in lets it twist.
- Clip loose threads as you go; a garment finished clean inside lasts longer and looks professional.

Check your work

- ☐ I sewed the pants in a sensible order with finished seams and a reinforced crotch.
- ☐ The casing is even, the elastic is joined flat and secured, and the hems are straight.
- ☐ I kept a complete construction log and calculated the true cost.

LAB NOTEBOOK

1. Draw the order of construction as a numbered flowchart with a small sketch at each step.
2. Tape in a fabric swatch, a short piece of the elastic and your cost table.
3. Write your construction log and three improvements for next time.

KEY FORMULAS

$$\text{elastic cut length} = \text{waist} - \text{reduction} + \text{overlap}$$

$$\text{elastic cut length} = \text{waist} - \text{reduction} + \text{overlap}$$

$$\text{casing depth} = \text{elastic width} + \frac{1}{4} \text{ to } \frac{3}{8} \text{ in}$$

$$\text{casing depth} = \text{elastic width} + 41 \text{ to } 83 \text{ in}$$

$$\text{cost per garment} = \sum (\text{quantity} \times \text{unit price})$$

$$\text{cost per garment} = \sum (\text{quantity} \times \text{unit price})$$

From history. Thomas Hancock's "masticator," a spiked roller in a drum that tore and kneaded scrap rubber into a solid block, was kept secret for years; his workers called it the pickle. Rubber elastic from Hancock's works went into braces (suspenders), garters and the elastic-sided boots popular in Victorian England.

WORKED EXAMPLES

Example 1. The waist is 31 in. Cut elastic 3 in shorter with a 1-in overlap. For 1¼-in elastic, how deep is the casing, and how much allowance is folded at the waist (casing depth doubled plus a ¼-in turn-under)?

Show solution

1. Elastic: $31 - 3 + 1 = 29$ in $31 - 3 + 1 = 29$ in.
2. Casing depth: $1.25 + 0.25 = 1.5$ in $1.25 + 0.25 = 1.5$ in.
3. Allowance: $2 \times 1.5 + 0.25 = 3.25$ in $2 \times 1.5 + 0.25 = 3.25$ in.

Answer: 29 in of elastic; a 1½-in casing; 3¼ in folded at the waist.

Example 2. Pajama pants use 2½ yd of flannel at \$7.99, 1 yd of elastic at \$1.29, and about 120 yd of thread from a \$4.50, 500-yd spool. Find the cost.

Show solution

1. Flannel: $2.5 \times 7.99 = 19.98$ $2.5 \times 7.99 = 19.98$; elastic 1.29; thread $\frac{120}{500} \times 4.50 = 1.08$ $120 \times 4.50 = 1.08$.
2. Total: $19.98 + 1.29 + 1.08 = 22.35$ $19.98 + 1.29 + 1.08 = 22.35$.

Answer: About \$22.35, not counting your time or the machine.

Example 3. A crotch seam is 26 in long from front waist to back waist, sewn twice at 2.5 mm. About how many stitches is that, and why sew it twice?

Show solution

1. One row: $26 \times 25.4 \div 2.5 \approx 264$ stitches $26 \times 25.4 \div 2.5 \approx 264$ stitches; two rows ≈ 528 .
2. The curved seam takes the most strain; a second row shares the load and protects the seam if one row breaks.

Answer: About 530 stitches; double stitching reinforces the most stressed seam in the pants.

PRACTICE

1. **Easy** Who patented elastic fastenings in 1820?
Show answer
Thomas Hancock.
2. **Easy** What process made rubber stable in heat and cold, and who discovered it?
Show answer
Vulcanization; Charles Goodyear (1839, patented 1844), developed also by Hancock.
3. **Easy** Which elastic narrows when stretched and suits casings?
Show answer
Braided elastic.
4. **Medium** Waist 27 in, cut 2 in shorter, 1-in overlap. Elastic length?
Show answer
26 in.
5. **Medium** Casing depth for $\frac{3}{4}$ -in elastic (add $\frac{1}{4}$ in)?
Show answer
1 in.
6. **Medium** List the order of construction for pajama pants.
Show answer
Inseams, crotch seam, press and finish, casing, elastic, hems.
7. **Medium** How do you keep elastic from twisting in the casing?
Show answer
Distribute gathers evenly and stitch through casing and elastic at the side seams or stitch in the ditch at seams.
8. **Hard** $2\frac{7}{8}$ yd of fabric at \$6.49, elastic \$1.10, thread \$1.25. Cost?
Show answer
 $18.66 + 1.10 + 1.25 = \$21.01$
 $18.66 + 1.10 + 1.25 = \$21.01$
9. **Hard** Why is the crotch curve reinforced rather than deeply clipped?
Show answer
Clipping weakens a seam that takes great strain; a second row of stitching and trimming below it lets the curve lie flat while keeping strength.
10. **Hard** Elastic that is too long makes pants slip; too short, they pinch. A 30-in waist feels best with elastic of 27 in finished. What reduction is that, and what do you cut with a 1-in overlap?
Show answer
3 in reduction; cut 28 in.
11. **Challenge** Compare making your pajama pants with buying a similar pair for \$24. Include materials, time and what you gain beyond money.
Show answer
Materials may cost about the same or less; time is several hours. Gains: fit made for you, quality seams, fabric you chose, skill, and the ability to make more (or for others) faster each time.

COMMON MISTAKES

- Sewing the crotch seam leg by leg. Slip one leg inside the other and sew the whole curve at once.
- Letting the elastic twist while threading it. Pin the trailing end outside the casing and check it flat every few inches.
- Skipping prewashing. Shrunken pajamas after one wash waste all your fitting work.

Make it a game · Order Up. Write each construction step for pajama pants on a card and shuffle. Players race to put them in the right order. Then the same with a vest. A parent checks; one wrong card costs ten seconds. Best time wins, and the winner must explain why one tricky step comes where it does.

9.3 JUDSON, SUNDBACK AND THE ZIPPER

OBJECTIVES

- Tell the history of the zipper from Whitcomb Judson's clasp locker (1893) to Gideon Sundback's hookless fastener (1913–1917).
- Name zipper parts and types and insert centered and lapped zippers neatly.
- Calculate zipper lengths, teeth per inch and pouch dimensions.

Warm-up. Find three zippers: on a jacket, a pair of pants and a bag. Look at the teeth under the magnifier. Are they metal, molded plastic or coil? Zip one slowly and watch how the slider joins the two sides.

WATCH

Inserting a Lapped Zipper for Beginners | Sewing Tutorial with Callie Works-Leary

Craftsy • 5:37

<https://www.youtube.com/watch?v=O3cgrHnvd8w>

WHEN TO WATCH

Watch with your zipper, fabric and zipper foot ready; pause after each step and sew it.

BACKUP VIDEO

HISTORY ERASED | Zipper

The HISTORY® Channel Canada • 1:58

<https://www.youtube.com/watch?v=UFyb3XI3IGw>

A short history of the zipper, for after the story.

KEY TERMS

zipper tape and teeth

The woven fabric strips on each side, and the interlocking elements (metal teeth, molded plastic teeth or a continuous coil) attached to them.

stops

Small metal or plastic pieces at the ends of the teeth that keep the slider from running off.

lapped zipper

A zipper set with one folded edge covering the teeth, stitched on one side only, as in many skirts.

slider and pull

The part that moves along the teeth, meshing or separating them, and the tab you hold.

centered zipper

A zipper set in a seam with the two folded edges meeting over its center and stitching on both sides.

zipper foot

A narrow presser foot that lets the needle stitch close beside the zipper teeth.

CORE IDEAS

The story. Fastening boots and clothes with long rows of buttons or hooks was slow work. In 1893 Whitcomb Judson, a Chicago engineer, patented a “clasp locker,” a row of hooks and eyes closed by a sliding guide, meant for shoes. It worked poorly, popping open and jamming, and few people bought it. His company kept trying, and in 1906 it hired Gideon Sundback, a Swedish-born electrical engineer. In 1913 Sundback designed the “Hookless Fastener No. 2”: small nested teeth, each with a dimple and a bump, fixed to fabric tapes and joined by a slider. He patented it as the separable fastener in 1917, and he also built the machine that made it.

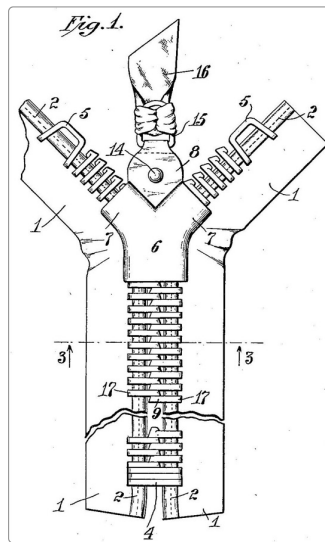
How they figured it out. Sundback's insight was to make every tooth identical and to let the slider force each tooth's bump into the next one's dimple from the other side, so the teeth interlock tightly and hold under pull but separate easily when the slider spreads them. In 1923 the B.F. Goodrich company used the fastener on rubber galoshes and called them Zipper boots, for the sound they made; the name stuck. Zippers spread to pouches, money belts and luggage, and by the 1930s to children's clothes, pants and jackets.

The fabric science. A zipper is a precise little machine sewn into flexible cloth. Metal teeth are strongest and suit jeans and heavy jackets; molded plastic teeth are light and colorful; nylon coil zippers are flexible, smooth and suit skirts, pouches and invisible zippers. The tape must be sewn straight and the fabric eased evenly, or the zipper ripples or gapes. Interfacing or stay tape along the opening keeps light or stretchy fabric from stretching. Lengths are measured along the teeth from top stop to bottom stop, and you choose a zipper as long as the opening, or longer and shortened.

Inserting zippers. For a centered zipper, baste the seam closed along the opening, press it open, center the zipper face down on the allowances, and stitch around it from the right side with the zipper foot, then remove the basting. A lapped zipper covers the teeth with one folded edge for a neat look on skirts. Use the zipper foot, move the slider out of the way as you sew past it, and stitch both sides in the same direction to prevent rippling.

The studio lab. You will sew a centered and a lapped zipper sampler, then make a lined zippered pouch for your sewing tools (or a gift), with boxed corners from Lesson 9.1.

PICTURE STUDY



Separable Fastener (patent drawing), Gideon Sundback, 1917 · Patent drawing, ink on paper · U.S. Patent Office; image from Wikimedia Commons
Image: [Wikimedia Commons](#), public domain

Sundback's 1917 patent drawing shows the fastener that became the modern zipper: identical teeth, each with a bump and a hollow, clamped to fabric tapes, and a slider shaped to force them together.

Look closely

- Find a single tooth. Where is its bump and where is its hollow?
- Find the slider. How does its Y shape bring the two rows together?
- Look at the tape. How are the teeth attached?
- Count the views in the drawing. Why show the fastener from several angles?

Talk about it

1. Why would identical teeth be easier to manufacture and more reliable than Judson's hooks and eyes?
2. What happens if one tooth is bent? Look at a broken zipper and compare.
3. Sundback also built the machine that made zippers. Why might that have mattered as much as the design?

Safety first. Slow down when stitching near the slider and teeth; a needle striking a metal tooth can break and fly. Wear safety glasses if you sew across metal zippers, unplug the machine before changing to the zipper foot, and keep fingers clear of the narrow foot.

Zipper Samplers and a Lined Zipper Pouch

Question: Which zipper method gives the neatest result, and can you design a pouch to exact dimensions? You will sew two zipper samplers, then a lined, boxed-corner pouch.

You will need

- Two 7-in or longer coil zippers for samplers and one 9-in zipper for the pouch
- Muslin scraps; two 10 × 8 in pieces each of outer cotton (canvas or denim) and lining
- Interfacing (optional), the zipper foot, pins, a ruler and the iron

LINED ZIPPER POUCH WITH BOXED CORNERS

Finished size: One pouch about 9 in wide at the top, 6 in at the base, 2 in deep · About 90 minutes

Fabric and notions

- Two 10 × 8 in outer pieces (sturdy cotton) and two 10 × 8 in lining pieces
- One 9-in zipper (coil or plastic molded)
- Optional: two 10 × 8 in pieces of fusible interfacing for a firmer pouch

How to make it

1. Fuse interfacing to the outer pieces if using it.
2. Layer: outer piece right side up, zipper face down along the top edge, lining face down on top. Pin and sew with the zipper foot $\frac{1}{2}$ in from the edge. Fold the outer and lining back, wrong sides together, and press.
3. Repeat on the other side of the zipper with the second outer and lining pieces. Topstitch along both sides of the zipper.
4. Open the zipper halfway (important!). Pin outers right sides together and linings right sides together, with the zipper teeth folded toward the lining.
5. Sew around all edges at $\frac{1}{2}$ in, leaving a 4-in opening in the bottom of the lining. Box all four corners 2 in deep (Lesson 9.1).
6. Turn right side out through the opening, push out the corners, and edgestitch the opening closed. Tuck the lining in and press.

Fabric check: Medium-weight cotton canvas, denim or decorator cotton makes a sturdy pouch; quilting cotton needs interfacing. Avoid very thick fabric at the zipper ends, where layers pile up.

Steps

1. **Hypothesis.** Predict which sampler will look neater and whether your pouch will finish within $\frac{1}{4}$ in of its planned size.
2. **Centered sampler.** Baste a 7-in seam on muslin, press open, center the zipper, and stitch around it from the right side. Remove basting.
3. **Lapped sampler.** Insert a second zipper with a lapped application following your video.
4. Inspect both: straightness of stitching, even distance from teeth, ripples, coverage of the teeth.
5. Make the pouch following the pattern card, after calculating its finished size.
6. Measure the finished pouch and compare with the plan.
7. **Conclude.** Which application was neater for you? Where did the pouch differ from the plan, and why?
8. **Repeat round.** Make a second pouch as a gift, adjusting the cut size to fix any difference.

Tips

- Leaving the zipper half open before sewing the final seams is the most important step; otherwise you cannot turn the pouch.
- Glue-baste zipper tapes with a washable glue stick for perfectly straight stitching.
- Stitch past the slider by stopping with the needle down, lifting the foot and sliding the pull behind the needle.

Check your work

- ☐ I inserted centered and lapped zippers with straight, even stitching.

- ☐ I designed and calculated the pouch dimensions before cutting.
- ☐ My finished pouch opens and closes smoothly and is within $\frac{1}{4}$ in of plan, or I explained why not.

LAB NOTEBOOK

1. Draw and label a zipper: tape, teeth, slider, pull, top and bottom stops.
2. Draw cross-sections of a centered and a lapped zipper application.
3. Tape in both samplers and a photo of your pouch with its measurements.

KEY FORMULAS

$$\text{teeth per inch} = \frac{\text{number of teeth on one side}}{\text{tooth length in inches}} \times 2 \text{ (both sides interlock)}$$

$$\text{teeth per inch} = \text{tooth length in inches} \times \text{number of teeth on one side} \times 2 \text{ (both sides interlock)}$$

$$\text{panel width} = \text{zipper length} + 2 \times \text{seam allowance}$$

$$\text{panel width} = \text{zipper length} + 2 \times \text{seam allowance}$$

From history. Sundback's company, the Hookless Fastener Company, later renamed Talon, made zippers in northwestern Pennsylvania. During World War II zippers were needed for flight suits, boots and equipment, and the zipper became one of the most common small machines in the world.

WORKED EXAMPLES

Example 1. A 7-in zipper has 42 teeth on each side along $6\frac{1}{2}$ in of teeth. How many teeth interlock per inch of closed zipper?

Show solution

1. Teeth per inch on one side: $42 \div 6.5 = 6.4642 \div 6.5 = 6.46$.
2. Both sides interlock alternately: $6.46 \times 2 \approx 12.9$ per inch $6.46 \times 2 \approx 12.9$ per inch.

Answer: About 13 teeth per inch of closed zipper.

Example 2. You want a pouch 9 in wide (finished) with a 9-in zipper along the top, $\frac{1}{2}$ -in seam allowances and 2-in boxed corners. What size do you cut the outer pieces if the finished height is 6 in?

Show solution

1. Width: $9 + 2 \times 0.5 = 10$ in $9 + 2 \times 0.5 = 10$ in.
2. Boxed corners take the depth from the height: add half the box depth to the height: $6 + 1 + 2 \times 0.5 = 8$ in $6 + 1 + 2 \times 0.5 = 8$ in.

Answer: Cut each outer and lining piece 10×8 in; the boxed corners give a 2-in-deep base.

Example 3. A skirt opening needs 7 in, but the store has only 9-in coil zippers. How do you shorten one?

Show solution

1. Measure 7 in from the top stop along the coil and mark it.
2. Whipstitch by hand (or zigzag with stitch length 0) across the coil 8–10 times at the mark to make a new bottom stop.
3. Cut the zipper $\frac{3}{4}$ in below the new stop.

Answer: Make a new thread stop at 7 in and cut off the excess. (Metal zippers are shortened from the top with pliers instead.)

PRACTICE

1. **Easy** Who patented the clasp locker, and in what year?

Show answer

Whitcomb Judson, 1893.

2. **Easy** Who designed the modern zipper and in what year?

Show answer

Gideon Sundback, 1913 (patented 1917).

3. **Easy** Where did the name zipper come from?

Show answer

B.F. Goodrich's Zipper boots of 1923, named for the sound.

4. **Medium** A zipper has 60 teeth per side over 10 in. Teeth per inch closed?

Show answer

12.

5. **Medium** Cut width for a 12-in-finished pouch with $\frac{5}{8}$ -in seams?

Show answer

13 $\frac{1}{4}$ in.

6. **Medium** Which zipper type suits jeans, which a light skirt? Why?

Show answer

Metal for jeans (strength); nylon coil for a skirt (light, flexible, smooth).

7. **Medium** Why use a zipper foot?

Show answer

It lets the needle stitch close to the teeth without riding over them.

8. **Hard** Why stitch both sides of a zipper in the same direction?

Show answer

Stitching in opposite directions shifts the layers in opposite ways and makes the zipper ripple or twist.

9. **Hard** A lapped zipper: which edge covers the teeth, and where is the visible stitching?

Show answer

One folded edge (usually the left side as worn) laps over the teeth; stitching shows only on that side, parallel to the fold and across the bottom.

10. **Hard** A pouch cut 10×8 in with $\frac{1}{2}$ -in seams and 3-in boxed corners: finished width, height and depth?

Show answer

Width $9 - 3 =$ about 6 in at the base (9 in at the top), height about $8 - 1 - 1.5 = 5.5$ in, depth 3 in.

11. **Challenge** Judson's clasp locker failed but led to Sundback's success. What does the zipper's history teach about inventions that do not work at first?

Show answer

A flawed first version can define the problem and gather the people and money to solve it; persistence, careful redesign (identical nesting teeth) and better manufacturing turned an idea into a success decades later.

COMMON MISTAKES

- Closing the zipper before sewing the pouch's final seams. Leave it half open.
- Stitching too close to the teeth so the slider jams, or too far so the teeth show.
- Shortening a metal zipper with scissors. Remove teeth from the top with pliers or buy the right length.

Make it a game · Zipper Detective. Set a timer for five minutes. Players hunt the house for zippers and score points by type: coil (1), molded plastic (2), metal (2), invisible (3), separating zipper on a jacket (3). Then each player must name the application (centered, lapped, fly, invisible) of one zipper they found.

9.4 FACINGS, COLLARS AND SLEEVES

OBJECTIVES

- Explain how interfacing, facings and linings finish edges, and how understitching, clipping and notching make curves lie flat.
- Describe how collars and set-in sleeves are constructed and how sleeve-cap ease is distributed.
- Cut, interface, and bag-line the shell and lining of a vest, calculating ease and curve treatments.

Warm-up. Look inside the neckline of a dress shirt or blouse and a T-shirt. How is each neckline edge finished? Find any stitching just inside the edge that does not show from outside. What might it be for?

WATCH

How to sew a vest with lining | sewing | learn to sew

[Simplicity Video](#) · 6:59

<https://www.youtube.com/watch?v=bDqUdPOauTU>

WHEN TO WATCH

Watch the lining bagged to the vest shell and turned through the shoulders before you sew yours; pause at each step.

BACKUP VIDEO

How to Sew a Set-In Sleeve - 2 ways | How to Ease a Sleeve

[The Awl-Nighter](#) · 4:34

https://www.youtube.com/watch?v=9E1_NcRrDB8

For the shirt option: watch how a sleeve cap is eased into the armhole.

KEY TERMS

interfacing

A layer (fusible or sew-in, woven or nonwoven) added inside collars, facings, cuffs and buttonhole areas to give body and support.

understitching

Stitching the facing to the seam allowances close to the seam, so the facing rolls to the inside and stays hidden.

bagging (a lining)

Sewing a lining to a garment's edges right sides together and turning it through an opening, so the lining acts as a facing.

facing

A shaped piece sewn to an edge (neckline, armhole, front) and turned inside to finish it cleanly.

clip and notch

Clipping (slits) lets inward (concave) curves spread; notching (removing wedges) lets outward (convex) curves lie flat without bulk.

sleeve-cap ease

The extra length of the sleeve cap's seamline compared with the armhole, eased in smoothly so the sleeve fits over the shoulder's curve.

CORE IDEAS

The story. In 1827 in Troy, New York, Hannah Lord Montague, a blacksmith's wife tired of washing her husband's whole shirt when only the collar was soiled, snipped the collar off, washed it, and sewed on ties so it could be attached and removed. Detachable collars caught on, and Troy's collar and shirt factories grew so large that the city became known as the Collar City. Starched separate collars stayed in fashion for nearly a century. Her idea rested on a simple fact every shirtmaker knows: the collar is the hardest-working, most visible piece of a shirt, and its construction must be exact.

How they figured it out. Tailors and shirtmakers learned that edges stay crisp only with support and the right finish. A collar has an upper and under collar, usually with interfacing between, sewn edge to edge, trimmed, turned and pressed so the seam rolls slightly to the underside. Facings work the same way at necklines and front edges; understitching holds them inside. A set-in sleeve is cut

with a cap slightly longer than the armhole it fits, about 1 to 1½ in in a woven shirt, and that extra is eased in so the cap rounds over the top of the arm with no tucks or puckers.

The fabric science (of curves). When a curved seam is turned, the allowance must take a different length than the seamline. On an inward (concave) curve, like a neckline, the allowance edge is shorter than it needs to be once turned, so you clip slits to let it spread. On an outward (convex) curve, like a collar's rounded edge, the allowance edge is too long once turned, so you notch out small wedges to remove the excess. Grading (trimming the layers of an allowance to different widths) prevents a ridge. Easing a sleeve cap works because woven fabric can be compressed slightly along the bias: steam shrinks the eased area into a smooth curve.

The vest. A lined vest has no collar or sleeves, which makes it an ideal first jacket-like garment: the lining is bagged to the shell along the front, neck, hem and armholes, so the lining itself finishes every edge. Interfacing goes along the fronts where buttonholes will be. The vest then turns right side out through the shoulders or a side opening, a satisfying moment of tailoring geometry.

The studio lab. You will cut, mark and interface your vest's shell and lining, bag them together along the edges, clip and notch curves, understitch where you can, turn and press. (Shirt option: interface and sew the collar and stand and set in one sleeve.) Lesson 9.5 finishes it with buttonholes and buttons.

PICTURE STUDY



Waistcoat Panel (unsewn, embroidered to shape), Unknown embroiderers, France or England, 18th century · Silk, embroidered with silk thread · The Metropolitan Museum of Art, New York

Image: [Wikimedia Commons](#), public domain

In the 1700s, fine waistcoat fronts were often embroidered to shape on a length of silk before they were ever cut: the embroiderer worked the borders, pocket flaps and buttonholes into the outline of the pattern piece, and a tailor later cut it out and made it up for a customer. This panel was never made up, so it shows the flat pattern shape of a waistcoat front.

Look closely

- Find the outline of the waistcoat front. Where are the neckline, the front edge and the hem?
- Find the pocket flaps and any embroidered buttonholes. How are they spaced?
- Look at the borders. Why would the embroidery follow the edges a facing will finish?
- Compare its shape with your vest pattern. What is the same, and what has changed in 250 years?

Talk about it

1. Why would an embroiderer work the design before the piece was cut out?
2. Where would the tailor add interfacing, and why?
3. What would it take to turn this flat panel into a finished, lined waistcoat?

Safety first. Fusible interfacing is applied with a press cloth so adhesive does not coat the iron; keep the iron upright between uses and unplug it after. Use small, sharp scissors for clipping, cutting toward the stitching but never through it, away from your fingers.

Build the Lined Vest (Shell, Lining and Bagging)

Question: Can you bag a lining to a vest shell so every edge is smooth, flat and invisible from the outside? You will cut, interface, sew, bag, clip, turn and press your vest; buttonholes come in Lesson 9.5.

You will need

- A lined vest pattern (commercial or drafted from a fitting vest), adjusted from your measurements
- About 1¼ yd of shell fabric (cotton twill, linen, wool flannel or brocade), 1¼ yd of lining (cotton lawn, rayon or polyester lining), ½ yd of fusible interfacing
- Thread, pins, a point turner, small sharp scissors, the iron, a press cloth and the ham

BAG-LINED VEST (CONSTRUCTION TO THE TURNED STAGE)

Finished size: One vest fitted to the wearer · About 4–5 hours over two sessions

Fabric and notions

- Shell: two fronts and one back (or two backs) cut on grain
- Lining: the same pieces cut from lining fabric
- Interfacing: front pieces (or front edges) fused to the shell fronts

How to make it

1. Fuse interfacing to the wrong side of the shell fronts with a press cloth.
2. Sew any darts in shell and lining; press them in opposite directions to reduce bulk.
3. Sew the shell shoulder seams; sew the lining shoulder seams. Press open.
4. Lay shell and lining right sides together. Sew around the front edges, neckline and front hem, and around both armholes, at the pattern's seam allowance. Leave the side seams open.
5. Grade the allowances, clip the concave curves, notch the convex ones and trim the corners. Understitch the lining as far as you can reach.
6. Turn the vest right side out by pulling each front through the shoulders to the back. Push out the points with the point turner and press so no lining shows.
7. Sew the side seams: shell to shell and lining to lining in one continuous seam, leaving a 4-in opening in one lining side. Turn, close the opening by hand with a slip stitch or by edgestitching, and press.

Fabric check: A firm woven shell (cotton twill, linen, wool flannel, decorator brocade) sews and presses crisply. The lining should be lighter and smooth, so the vest slides over a shirt. Prewash cotton shell and lining together so they shrink alike; wool shell and rayon or acetate linings are dry-cleaned or steamed instead.

Steps

1. **Hypothesis.** Predict where the vest is most likely to show lining or puckers after turning.
2. Check the pattern against your measurements and ease preference; adjust if needed (Lesson 8.4).
3. Cut and mark the shell, lining and interfacing on grain.
4. Construct the vest following the pattern card, pressing every seam before the next.
5. **Shirt option.** If making a button-front shirt instead, interface and sew the collar and stand, attach them, and set in one sleeve, measuring the cap ease first.
6. Inspect the turned vest: edges flat, no lining showing, points crisp, armholes smooth. Fix any spot by re-pressing or re-stitching.
7. Record time, problems and fixes in your construction log.
8. **Conclude.** Which step did clipping, notching and understitching help most? What would you change?

Tips

- Before turning, test one armhole: pull it through and look. Fixing a seam is easy now and hard later.
- Press the edges with the lining rolled slightly to the inside, a press cloth on top.

- Choose a vest pattern with separate side seams if this is your first bagged garment.

Check your work

- ☐ I interfaced, sewed and bagged the vest with smooth curves and crisp points.
- ☐ No lining shows at the edges, and all seams are pressed.
- ☐ I recorded the construction steps, time and fixes in my log.

LAB NOTEBOOK

1. Draw a concave and a convex curve with clips and notches shown.
2. Draw a cross-section of a bagged vest edge: shell, interfacing, seam, lining, understitching.
3. Write the order of construction for your vest (or shirt) as a numbered list.

KEY FORMULAS

$$\begin{aligned} \text{sleeve-cap ease} &= \text{cap seamline length} - \text{armhole seamline length} \\ \text{sleeve-cap ease} &= \text{cap seamline length} - \text{armhole seamline length} \\ \text{ease per inch} &= \frac{\text{cap ease}}{\text{length of the eased section}} \\ \text{ease per inch} &= \text{length of the eased section} \end{aligned}$$

From history. The Troy collar makers grew into large firms. One of them, Cluett, Peabody and Company, sold its shirts and collars under the Arrow name and later developed the Sanforizing process you met in Unit 6, so that a shirt bought in its size would stay that size.

WORKED EXAMPLES

Example 1. A shirt sleeve cap measures $19\frac{1}{4}$ in along the seamline; the armhole measures 18 in. Find the cap ease and the ease per inch if it is spread over the top 8 in of the cap.

Show solution

1. Ease: $19.25 - 18 = 1.25$ in $19.25 - 18 = 1.25$ in.
2. Per inch: $1.25 \div 8 \approx 0.16$ in $1.25 \div 8 \approx 0.16$ in, about $5/32$ in per inch.

Answer: $1\frac{1}{4}$ in of ease, about $\frac{1}{8}$ – $\frac{3}{16}$ in eased into each inch of the top 8 in: easy to ease with steam, no tucks.

Example 2. A curved neckline seam has a $\frac{5}{8}$ -in allowance. If you clip every $\frac{1}{2}$ in around a 10-in curve, how many clips? Why not clip every 2 in?

Show solution

1. $10 \div 0.5 = 20$ clips $10 \div 0.5 = 20$ clips.
2. At 2-in spacing the allowance would spread only at five points and the curve would show bumps; frequent, shallow clips (to within $\frac{1}{8}$ in of the stitching) let it lie smooth.

Answer: About 20 clips; close spacing keeps the curve smooth.

Example 3. A vest's front edges and hem total 72 in of seams to be bagged, plus 22 in at the armholes. At 10 stitches per inch, how many stitches, and how much thread at a ratio of 2.5?

Show solution

1. Seams: $72 + 22 = 94$ in $72 + 22 = 94$ in; stitches $94 \times 10 = 940$ $94 \times 10 = 940$.
2. Thread: $94 \times 2.5 = 235$ in ≈ 6.5 yd $94 \times 2.5 = 235$ in ≈ 6.5 yd.

Answer: About 940 stitches and $6\frac{1}{2}$ yd of thread for the bagging seams alone.

PRACTICE

1. **Easy** Who invented the detachable collar, where and when?

Show answer

Hannah Lord Montague, Troy, New York, 1827.

2. **Easy** What does understitching do?

Show answer

It holds the facing's seam allowances to the facing so the facing rolls inside and stays hidden.

3. **Easy** Do you clip or notch a concave curve?

Show answer

Clip.

4. **Medium** A cap is $18\frac{3}{4}$ in, the armhole $17\frac{1}{2}$ in. Find the cap ease.

Show answer

$1\frac{1}{4}$ in.

5. **Medium** Why is interfacing placed where buttonholes will go?

Show answer

It supports the fabric so buttonholes do not stretch, pucker or fray.

6. **Medium** What is grading a seam allowance, and why do it?

Show answer

Trimming each layer of the allowance to a different width so the layers do not form a ridge on the right side.

7. **Medium** Why does a collar seam roll slightly to the underside?

Show answer

The upper collar is cut or pressed a little larger so the seam hides underneath and the edge looks crisp.

8. **Hard** A cap ease of 2 in is spread over 9 in. Ease per inch? Is that easy or hard to ease without tucks in a firm cotton?

Show answer

About 0.22 in per inch; hard in firm cotton (likely to pucker); reduce cap ease or spread it farther.

9. **Hard** Explain how a bagged lining finishes a vest's edges without separate facings.

Show answer

The lining is sewn to every edge right sides together and turned; the seams lie at the edges with the lining inside, so the lining acts as the facing for fronts, neck, hem and armholes.

10. **Hard** Why can steam help ease a sleeve cap?

Show answer

Steam relaxes and slightly shrinks the woven fabric along the bias of the cap, molding the eased fullness into a smooth curve.

11. **Challenge** Hannah Montague's idea saved washing. Estimate how much laundry a man's detachable collar saved if a shirt body could be worn three days while the collar was changed daily, for 300 days a year.

Show answer

Without detachable collars: about 300 shirt washes; with them: about 100 shirt washes plus 300 small collar washes, saving about 200 full-shirt washes a year, a large saving of water, soap, fuel and labor.

COMMON MISTAKES

- Clipping through the stitching. Clip to within $\frac{1}{8}$ in, never through.
- Sewing the side seams before bagging. Leave them open so the vest can turn.
- Forgetting to grade and trim. Bulky edges never press flat.

Make it a game · Clip or Notch? A parent draws or holds up curves (necklines, collar points, armholes, pocket corners, scallops). Players shout “clip,” “notch” or “trim” as fast as they can. One point per correct call, and a bonus for explaining why with the words inward and outward.

9.5 BUTTONHOLES, BUTTONS AND HEMS

OBJECTIVES

- Tell a short history of buttons and buttonholes and describe machine and hand-worked buttonholes.
- Space, size and sew buttonholes and buttons (with thread shanks) accurately, and choose and sew suitable hems.
- Finish the vest (or shirt), calculating button spacing, buttonhole length and hem allowances.

Warm-up. Look at the buttons on three garments. Are they sewn flat, or do they stand on a little stem of thread? Measure one button and its buttonhole. How much longer is the hole than the button?

WATCH

How To Sew With a One Step Buttonhole Foot

Professor Pincushion · 3:49

<https://www.youtube.com/watch?v=Tf7mE7EiZQk>

WHEN TO WATCH

Watch with your machine's buttonhole foot and a scrap; sew a test buttonhole as you follow along.

BACKUP VIDEO

How to sew a hand-sewn buttonhole Easy to understand with illustrations

Minoru Sews · 5:48

https://www.youtube.com/watch?v=jBowd_m6rkg

A hand-worked buttonhole, stitch by stitch; try one on your sampler.

KEY TERMS

buttonhole stitch

A hand stitch that forms a small knot (purl) along the edge of a slit, protecting it from fraying.

thread shank

A short stem of wound thread under a sew-through button that lifts it so the buttonhole's layer can lie underneath.

blind hem

A hem stitched so that only tiny, nearly invisible stitches show on the right side.

one-step buttonhole

A machine buttonhole sewn automatically to the button's size, using a buttonhole foot that holds the button.

button spacing

The even distance between buttons, set from the top and bottom buttons and divided equally.

hem allowance

The fabric turned up for a hem; wider on straight hems and heavy fabrics, narrower on curves.

CORE IDEAS

The story. Buttons are ancient, but for most of history they were ornaments or fastened through loops. Buttonholes, slits finished with stitching so a button can pass through, appear in Europe in the 1200s, and they changed clothing: garments could now close snugly down the front and be fitted closely. Rows of tiny buttons became a mark of skilled work. Tailors' apprentices spent years perfecting hand-worked buttonholes, and in the late 1800s machine makers built buttonhole machines for factories and, later, buttonhole attachments for home machines. Today most home machines sew a buttonhole in one step, but a hand-worked buttonhole is still the sign of fine tailoring.

How they figured it out. A buttonhole is a deliberate cut in the cloth, so it must be strong where the button pulls and protected all along its edges. Machine buttonholes use dense zigzag (satin) stitches along both sides and bar tacks across the ends. Hand buttonholes use the buttonhole stitch, each one tied with a little knot at the edge. Both need interfacing behind them. The length must let the button pass easily but not slip out: roughly the button's diameter plus its thickness. Buttons on thick fabric need a thread shank, so the fabric of the buttonhole side has room to lie flat underneath.

The fabric science (of spacing and hems). Buttons are spaced evenly between a top button (near the neckline) and a bottom button (above the hem), with extra buttons placed at points of strain. On a vest, buttonholes run horizontally on a front closure so the strain pulls toward the end of the hole, not along it. Hems depend on the fabric and shape: a double-fold hem for pajama pants, a narrow rolled hem for lightweight curves, a blind hem for skirts and trousers where stitches should not show. Curved hems need a narrow allowance, since a wide one must be eased.

Finishing well. The last details are the first things people see. Mark buttonholes exactly, test one on a scrap of the same layers, cut them open with a seam ripper and a pin across the end as a stop, and sew buttons with a shank and a few tight stitches through the shank. Press the finished garment, trim every thread, and try it on.

The studio lab. You will sew a buttonhole sampler (machine and one hand-worked) and a hem sampler, then finish your vest (or shirt) with evenly spaced buttonholes and shank-sewn buttons, completing the unit's garment.

PICTURE STUDY



The Diligent Mother (La Mère laborieuse), Jean-Siméon Chardin, 1740 · Oil on canvas · Nationalmuseum, Stockholm (another version in the Louvre)

Image: [Wikimedia Commons](#), public domain

Chardin shows a mother examining her daughter's embroidery, pointing out a mistake, while the girl stands beside her, a little abashed. A dog curls nearby and a winding frame stands in the corner. It is a picture of teaching and of finishing well: work is not done until it has been checked.

Look closely

- Find the embroidery the mother is checking. What might she have found?
- Find the winding frame or skein. What is it for?
- Look at the daughter's face and hands. How does she feel?
- Find the dog and the domestic details. What kind of household is this?

Talk about it

1. What does checking the work have to do with finishing a garment with buttonholes and hems?
2. Why might a mother point out a mistake rather than fix it herself?
3. What would you want a teacher to check on your finished vest?

Safety first. Use the seam ripper away from your body, with a pin across the buttonhole end as a stop. Keep fingers clear of the needle while the machine sews a buttonhole automatically. Sew buttons with the needle pointed away from you and count needles and pins back in.

Finish the Vest: Buttonholes, Buttons and Hems

Question: Can you place, size and sew buttonholes and buttons so the vest closes smoothly and evenly? You will sew samplers, then finish and wear your vest (or shirt).

You will need

- Your turned vest (or shirt) from Lesson 9.4
- Buttons (vests usually take 4–6; $\frac{5}{8}$ – $\frac{3}{4}$ in), matching thread, a buttonhole foot, a seam ripper, pins
- Scraps of the vest shell with interfacing for test buttonholes, a ruler and chalk

Steps

1. **Hypothesis.** Predict the buttonhole length and spacing your buttons need.
2. **Samplers.** On a scrap with the same layers as the vest front, sew three machine buttonholes and one hand-worked buttonhole. Cut them open and test the button through each.
3. Sew a hem sampler: double-fold, blind hem (by machine or hand) and a narrow rolled hem on a curve.
4. Calculate button spacing for the vest front and mark buttonhole positions on the buttonhole side with chalk (horizontal, starting $\frac{1}{8}$ in past the center-front line toward the edge).
5. Sew the buttonholes, cut them open with a pin stop, and dab any loose threads.
6. Lap the fronts, mark the button positions through the buttonholes, and sew the buttons with thread shanks.
7. Press the vest, try it on over a shirt, and check: fronts even, buttons aligned, no gaping.
8. **Conclude.** How did your sampler results change your plan? What is the best feature of your finished vest, and what would you improve?
9. **Repeat round.** If a buttonhole is crooked or a button misplaced, fix it: a crooked button is unpicked and moved; a bad buttonhole can be covered by a slightly larger button or reworked by hand.

Tips

- Always test the buttonhole on the same layers as the garment, interfacing included.
- A toothpick laid across the button while sewing makes an even thread shank; remove it and wind the thread around the stitches.
- Sew the top button first and check the fit before the rest.

Check your work

- ☐ I sewed and tested machine and hand-worked buttonholes and three hems.
- ☐ My vest's buttonholes are evenly spaced and sized, and the buttons have shanks.
- ☐ The finished vest fits, closes evenly and is pressed and trimmed.

LAB NOTEBOOK

1. Draw a machine buttonhole and a hand-worked buttonhole, labeling bar tacks and purl edge.
2. Write your button spacing calculation and mark positions on a sketch of the vest front.
3. Tape in your buttonhole and hem samplers and a photo of the finished vest worn.

KEY FORMULAS

$$\text{spacing} = \frac{\text{distance from first to last button}}{\text{number of buttons} - 1}$$

$$\text{spacing} = \text{number of buttons} - 1 \text{ distance from first to last button}$$

$$\text{buttonhole length} \approx \text{button diameter} + \text{button thickness}$$

$$\text{buttonhole length} \approx \text{button diameter} + \text{button thickness}$$

From history. Before buttons and buttonholes spread, close-fitting garments were laced or sewn shut each time they were worn. Medieval laws sometimes limited how many buttons a person could wear, because rows of fine buttons were a display of wealth.

WORKED EXAMPLES

Example 1. A vest front has its top button 1 in below the neckline point and its bottom button 1½ in above the hem point; the front edge between those points is 16½ in. Space 5 buttons evenly.

Show solution

1. $\frac{16.5 \text{ in}}{5 - 1} = 4.125 \text{ in}$ $5 - 1 = 4$ $4.125 \text{ in} \times 4 = 16.5 \text{ in}$

2. Positions from the top button: 0, 4¼, 8½, 12¾, 16½ in.

Answer: Buttons every 4¼ in.

Example 2. A button is ¾ in across and ⅛ in thick. How long should the buttonhole be? What if the button is domed, ¼ in thick?

Show solution

1. Flat: $0.75 + 0.125 = 0.875 \text{ in}$ $0.75 + 0.125 = 0.875 \text{ in}$

2. Domed: $0.75 + 0.25 = 1.0 \text{ in}$ $0.75 + 0.25 = 1.0 \text{ in}$

Answer: 7⁄8 in for the flat button, 1 in for the domed one. Always test on a scrap.

Example 3. Pajama pants should finish 40 in from waist to hem. The pattern piece measures 41 in from waist stitching line to hem fold with a double-fold hem of ½ in then 1½ in. How much do you trim from the hem edge before folding, if the try-on shows the hem fold should be 1 in higher?

Show solution

1. Move the hem fold up 1 in; the hem allowance (2 in) stays the same below the new fold.

2. Trim 1 in from the raw edge, then fold ½ in and 1½ in.

Answer: Trim 1 in, then fold the double hem as usual.

PRACTICE

1. Easy Roughly when did buttonholes appear in Europe?

Show answer

In the 1200s.

2. Easy Why does a button on a coat need a thread shank?

Show answer

To lift it so the thick buttonhole layer can lie flat beneath it.

3. Easy Which way do buttonholes run on a vest front closure, and why?

Show answer

Horizontally, so the strain pulls toward the end of the hole rather than along its length.

4. Medium Space 6 buttons over 20 in from first to last.

Show answer

4 in apart.

5. Medium Buttonhole for a 5⁄8-in button, 3⁄16 in thick?

Show answer

13⁄16 in.

6. **Medium** Name three hems and a good use for each.

Show answer

Double-fold (pajama pants), blind hem (skirts, trousers), narrow rolled hem (light, curved edges).

7. **Medium** Why is interfacing needed behind buttonholes?

Show answer

To support the cut so it does not stretch, fray or pucker.

8. **Hard** A shirt has buttons from 2½ in below the neck to 7 in above the hem on a 30-in front. Space 7 buttons.

Show answer

Distance $30 - 2.5 - 7 = 20.5$ in $30 - 2.5 - 7 = 20.5$ in; spacing $20.5/6 \approx 3.42$ in $20.5/6 \approx 3.42$ in (3 7/16 in).

9. **Hard** Why does a curved shirttail hem use a narrow allowance?

Show answer

A wide allowance on a curve is longer at its edge than the garment where it lies, so it ripples; a narrow one turns smoothly.

10. **Hard** How do you keep from cutting through the end of a buttonhole when opening it?

Show answer

Put a pin across the bar tack at the end as a stop and cut with a seam ripper from the other end toward it (or use a chisel cutter).

11. **Challenge** Why might a tailor still hand-work buttonholes on a fine wool coat when a machine is faster?

Show answer

Hand-worked buttonholes are more durable on thick wool, can be shaped (keyhole) to the button, lie flatter, and show craftsmanship; they also allow the slit to be cut before stitching in a way machines may not.

COMMON MISTAKES

- Spacing buttons by eye. Calculate and mark.
- Cutting a buttonhole open without a pin stop. One slip ruins a front.
- Sewing buttons flat on thick fabric. Make a shank, or the garment will pucker when buttoned.

Make it a game · Button Ladder. Give each player a strip of paper the length of a vest front and a set of five buttons. Race to mark evenly spaced button positions using only a ruler and a pencil. A parent checks with a calculator: the most even spacing (smallest error) wins. Second round: estimate buttonhole lengths for six mystery buttons.

Scripture. “Put on therefore, as the elect of God, holy and beloved, bowels of mercies, kindness, humbleness of mind, meekness, longsuffering;” (Colossians 3:12, KJV)

Paul uses the language of getting dressed for the virtues of a Christian life. As you button a garment you made, remember the qualities Scripture tells us to put on every day.

UNIT 9 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (7 pts)
Explain how a dart shapes flat cloth, and give two rules for sewing a smooth dart point.
2. (7 pts)
A waist edge of 17 in must finish at 14 in with two equal darts. Find each intake.
3. (7 pts)
Find the arc removed from a 24-in-diameter circle by a 40° wedge.
4. (7 pts)
List the order of construction for pajama pants and explain why the crotch seam is sewn in one curve.
5. (7 pts)
Waist 33 in; elastic 3 in shorter plus 1 in overlap; 1-in elastic with a casing $\frac{1}{4}$ in wider. Find elastic length and waist fold allowance (casing doubled + $\frac{1}{4}$ in).
6. (7 pts)
Tell the history of the zipper from 1893 to 1923.
7. (6 pts)
Cut size for a pouch finishing 10 in wide at the top with a 10-in zipper and $\frac{1}{2}$ -in seams, and 7 in tall with 2-in boxed corners.
8. (6 pts)
Distinguish centered and lapped zipper applications and give a use for each.
9. (7 pts)
When do you clip and when do you notch a curved seam? Why?
10. (6 pts)
A sleeve cap measures 20 in and the armhole $18\frac{3}{4}$ in. Find the cap ease and ease per inch over 9 in.
11. (6 pts)
Who was Hannah Lord Montague, and what did her idea show about construction?
12. (7 pts)
Space 5 buttons over 18 in from first to last, and size a buttonhole for a $\frac{7}{8}$ -in button $\frac{1}{8}$ in thick.
13. (6 pts)
Why do coat buttons need thread shanks?
14. (7 pts)
Choose hems for pajama pants, a wool skirt and a curved shirttail, with reasons.
15. (7 pts)
Short essay (5–7 sentences): Describe how your vest (or shirt) came together, the hardest step, and what you would teach a younger sewer about finishing well.

UNIT PROJECT: TWO FINISHED GARMENTS

Present your finished pajama pants and your lined vest (or button-front shirt), both made from patterns you fitted, sewn with finished seams and pressed. Wear them for a photograph and give one honest evaluation of fit and workmanship for each.

Include your construction logs (steps, times, unpicking), cost sheets, and the samplers from this unit (darts, zippers, buttonholes, hems), plus the basket and pouch. If you sewed a second pair of pajama pants for a family member, include its log too.

LOOK FOR	WHAT IT MEANS
Fit	Both garments fit comfortably with the intended ease and hang straight on grain.
Workmanship	Seams are straight and finished, darts and curves smooth, casing even, buttonholes neat and evenly spaced, hems straight.
Pressing and finish	Every seam is pressed, threads are trimmed, and no lining shows on the vest.
Records and cost	Construction logs and cost sheets are complete and accurate.
Improvement and service	Samplers show practice before the real garment; any garment made for someone else is documented.

ANSWER KEY

1. It removes a wedge so the edge shortens and the cloth becomes a shallow cone. Taper so the last stitches run off the fold; tie off instead of backstitching (and press over a ham).
2. $1\frac{1}{2}$ in.
3. $\frac{40}{360} \times \pi \times 24 \approx 8.4$ in $360 \times \pi \times 24 \approx 8.4$ in
4. Inseams, crotch seam, press/finish, casing, elastic, hem. One continuous curve gives a smooth, strong seam with no join at the crotch point.
5. 31 in; casing $1\frac{1}{4}$ in; allowance $2\frac{3}{4}$ in.
6. Judson patented the clasp locker in 1893 (it jammed and popped open). His company hired Gideon Sundback, who designed identical nesting teeth (Hookless Fastener No. 2) in 1913 and patented the separable fastener in 1917, also building the machine to make it. B.F. Goodrich's 1923 Zipper boots gave the name.
7. Width 11 in; height $7 + 1 + 1 = 9$ in $7 + 1 + 1 = 9$ in.
8. Centered: folds meet over the zipper center, stitching both sides (center-back seams, pouches). Lapped: one fold covers the teeth, stitching on one side (skirts, side openings).
9. Clip concave (inward) curves so the allowance can spread when turned; notch convex (outward) curves to remove excess that would bunch.
10. $1\frac{1}{4}$ in; about 0.14 in per inch.
11. A Troy, New York, woman who in 1827 invented the detachable collar; it showed the collar is the hardest-working, most visible part of a shirt, worth special construction and care.
12. $4\frac{1}{2}$ in apart; 1 in.
13. So the thick buttonhole layer can lie flat under the button without pulling or puckering.
14. Double-fold for pajamas (durable, encloses edge); blind hem for the skirt (invisible); narrow rolled hem for the curve (turns smoothly).
15. A good answer describes bagging, clipping and notching, turning, buttonholes and buttons from the student's own log, names a real difficulty and its fix, and gives sound advice (test on scraps, press every seam, check before cutting buttonholes).

TAILORING, ALTERATION AND THE CAPSTONE GARMENT

The last unit gathers everything you have learned into the work of a tailor: understanding cloth deeply enough to shape it, fit it and make it last. You will learn how tailors build structure into a garment with interfacing, hair canvas and pad stitching; how to alter store-bought clothes so they fit; how to mend skillfully, so that a torn or worn garment returns to service; and how care, repair and wise choices make clothing last, measured honestly with cost per wear and a make-or-buy comparison.

The year ends with a capstone garment that you design, pattern, fit in muslin and build, with a full construction log and cost analysis. It should be modest, useful and well made, and it may be for yourself or for someone else. Like Dorcas, whose coats and garments the widows of Joppa held up with tears, a sewer's best work is often what she or he makes for others.

PREREQUISITES

- Units 7–9: machine skills, patterns and fit, and garment construction
- Your measurement card, fitted pattern and construction logs
- A garment in need of alteration or mending, and a capstone plan approved by a parent

MASTERY CHECKLIST

- ☐ I can describe how interfacing, hair canvas and pad stitching shape and support a tailored garment, and measure fabric stiffness.
- ☐ I can alter a ready-made garment: hem, take in or let out a seam, and move buttons, calculating each change.
- ☐ I can mend a garment by darning, patching or invisible repair, choosing the method and preshrinking patches.
- ☐ I can calculate cost per wear and compare making and buying honestly.
- ☐ I can design, pattern, fit, construct and finish a capstone garment with a complete construction log and cost analysis.

OPTIONAL BOOKS AND TOOLS FOR THIS UNIT

- **Sew-in hair canvas or medium-weight woven interfacing:** A quarter yard is enough for the Lesson 10.1 samples; fabric stores and tailoring suppliers carry it.
- **A darning egg or mushroom:** Inexpensive and useful for life; a smooth light bulb (cold, unused) or a ladle works in a pinch.
- **A tailor's chalk and a seam gauge:** A 6-inch sliding seam gauge makes hems and alterations quick and exact.

Not required. Every project in this unit works with ordinary fabric-store supplies. School Launch has no ties to these authors, publishers or companies.

LESSONS IN THIS UNIT

10.1 The Tailor's Craft: Canvas and Pad Stitching	3 sessions of 50–90 minutes
10.2 Altering Store-Bought Clothes	3 sessions of 50–90 minutes
10.3 Mending: Dorcas and the Coats She Made	3 sessions of 50–90 minutes
10.4 Care, Cost per Wear and Make or Buy	3 sessions of 50 minutes
10.5 The Capstone Garment	3 sessions of 60–90 minutes (plus construction time over several weeks)

10.1 THE TAILOR'S CRAFT: CANVAS AND PAD STITCHING

OBJECTIVES

- Describe the tailor's trade from the guild shops of Renaissance Europe to the colonial tailor, and how tailored garments are built.
- Explain how interfacing, hair canvas and pad stitching add structure and shape, and when to choose fusible or sew-in support.
- Measure fabric stiffness with a cantilever test and calculate bending length and flexural rigidity.

Warm-up. Feel the front of a man's suit coat or a structured jacket between your fingers, then a T-shirt's front. Hold each by the shoulder and let it hang. What is inside the jacket that makes it hold its shape?

WATCH

18th-Century Tailoring in Colonial Williamsburg

[Colonial Williamsburg](#) · 6:45

<https://www.youtube.com/watch?v=J0mM5lsnC-c>

WHEN TO WATCH

After “The story.” Watch the master tailor cut and the journeymen sew, and note every hand tool you see.

BACKUP VIDEO

Pad Stitching Explained for Tailoring: The Complete Guide

[International School of Tailoring](#) · 13:59

<https://www.youtube.com/watch?v=GUVnHFRAHFg>

Watch pad stitching close up: notice how the stitches roll the canvas and cloth together over the hand.

KEY TERMS

interfacing

A supporting layer inside a garment that gives body and shape; it may be fused (glued by heat) or sewn in.

pad stitching

Small diagonal hand stitches that join canvas to cloth while the layers are rolled over the hand, building a permanent curve into lapels and collars.

bending length

A measure of fabric stiffness from the cantilever test: half the length of fabric that overhangs a table edge before it droops to a set angle.

hair canvas

A springy woven interfacing traditionally made with goat or horse hair in the weft, used in tailored coats to give resilient shape.

roll line

The line along which a lapel or collar folds back.

flexural rigidity

A fabric's resistance to bending, calculated from its weight per area and the cube of its bending length.

CORE IDEAS

The story. Around 1570 the painter Giovanni Battista Moroni, in Bergamo in northern Italy, painted a tailor at his work: a young man in a fine cream doublet and red breeches, shears in hand, looking up from a length of black cloth as if a customer had just come in. It is one of the first portraits of a craftsman at his trade, and the tailor holds his shears with the dignity of a gentleman. Tailors were organized in guilds that trained apprentices over years. In colonial Williamsburg, master tailors advertised for journeymen in the *Virginia Gazette*, and enslaved and free tailors cut and sewed coats, waistcoats and breeches for the town. The skills of measuring, cutting, canvassing and pressing passed from hand to hand.

How they figured it out. Wool cloth alone droops; a coat needs a frame inside it. Tailors learned to add a layer of stiff, springy canvas behind the coat front, chest and lapels, to sew it to the cloth with hundreds of tiny pad stitches while rolling both layers over the hand, and to press the shape in with steam. The canvas gives the chest its smooth curve, and the pad stitching sets the lapel's roll so it

returns to shape after every wearing. In the twentieth century, fusible interfacings, coated with heat-activated glue, made structure faster and cheaper for factories and home sewers; in fine tailoring, hand-sewn canvas still lasts longer and molds better.

The fabric science. Structure is about stiffness, how much a fabric resists bending. Stiffness rises steeply with thickness: doubling a fabric's effective thickness can make it many times stiffer. Interfacing adds stiffness without much weight, and hair canvas adds springiness (resilience), so the shaped area recovers after it is crushed. Textile labs measure stiffness with a cantilever test: a strip is slid off a horizontal platform until its tip droops to 41.5°; half the overhang is the bending length c , and the flexural rigidity is $G = Wc^3$, where W is the fabric's weight per area. Because of the cube, a small change in bending length means a large change in stiffness.

Choosing support. Fusible interfacing is quick and suits shirts, facings, waistbands and many jackets, but it can bubble if poorly fused and stiffens the fabric's hand. Sew-in interfacings and canvas keep the fabric's natural drape and can be shaped by pad stitching. The rule is that interfacing should support, not overpower: choose a weight equal to or a little lighter than the fashion fabric.

The studio lab. You will make four collar-sized samples of the same wool or cotton twill (no interfacing, fusible, sew-in and pad-stitched canvas), shape the last over your hand, and measure the stiffness of each with a homemade cantilever tester.

PICTURE STUDY



The Tailor (Il Tagliapanni), Giovanni Battista Moroni, c. 1565–70 · Oil on canvas · The National Gallery, London

Image: [Wikimedia Commons](#), public domain

Moroni painted this tailor in Bergamo around 1570. He stands at his table with large shears in hand over a length of black cloth, dressed in a fine cream doublet and red breeches, and he looks straight at us. Few painters of the time gave a working craftsman such a dignified portrait.

Look closely

- Find the black cloth on the table. What is he about to do with it?
- Look at his shears. How large are they, and how does he hold them?
- Look at his doublet: the slashes, the row of buttons, the ruffled collar and cuffs, the fit at the waist. What does his own clothing advertise?
- Notice his expression. Is he interrupted, proud, thoughtful?

Talk about it

1. Why would a tailor dress so carefully himself?
2. Cutting was the most skilled and costly step in the shop. Why would a tailor be painted cutting rather than sewing?
3. What would a tailor of 1570 and a tailor today have in common?

Safety first. Fusible interfacing is applied with a press cloth so glue does not reach the iron; keep the iron upright between uses and unplug it after. Hand needles for pad stitching are counted in and out of the pincushion, and pins are kept out of your mouth.

STUDIO LAB

Four Kinds of Structure and the Cantilever Test

Question: How much stiffness do different kinds of interfacing add, and how does pad stitching change the shape? You will make four samples and measure their bending length and flexural rigidity.

You will need

- Four 2 × 8 in strips and four 5 × 7 in collar samples of the same wool or cotton twill
- Fusible interfacing, sew-in interfacing and hair canvas (or a firm sew-in canvas)
- A hand needle and thread, a ruler, a protractor or a card cut to a 41.5° angle, a hardcover book or board for a platform, the scale and the iron

Steps

1. **Hypothesis.** Rank the four samples by stiffness and predict how much the fusible will add.
2. Prepare the samples: (A) no interfacing, (B) fusible fused to the back, (C) sew-in basted around the edges, (D) hair canvas pad stitched across the whole sample while rolling it over your hand. Make one strip and one collar sample of each.
3. **Cantilever tester.** Tape a card with a 41.5° line to the edge of a book so you can sight the angle. Lay a strip on the book and slide it slowly over the edge until its tip touches the 41.5° line. Measure the overhang. Repeat with each end and each face, four readings per strip.
4. Weigh each strip and calculate its weight per area (g/cm²). Calculate mean bending length and G for each sample.
5. Fold each collar sample along a roll line and let it hang. Photograph them side by side. Which holds a roll?
6. **Conclude.** Which support added the most stiffness? Which gave the best roll for a collar? What would you use in your capstone?
7. **Repeat round.** Steam-press sample D over a ham and let it cool. Did pad stitching plus pressing change its shape permanently?

Tips

- Slide the strip slowly; a quick push overshoots the line.
- Pad stitching goes faster than you think: small diagonal stitches, catching only a thread or two of the fashion fabric so nothing shows on the right side.
- Real textile labs use the same 41.5° method in a standard cantilever stiffness test.

Check your work

- ☐ I made four comparable samples, changing only the support.
- ☐ I measured bending length four times per strip and calculated G correctly.
- ☐ I explained which support suits which part of a garment.

LAB NOTEBOOK

1. Draw a cutaway of a tailored coat front: fashion fabric, canvas, pad stitching, lapel roll line, facing.
2. Tape in your four collar samples with their G values.
3. Write a one-paragraph guide to choosing interfacing for shirts, vests and coats.

KEY FORMULAS

$$c = \frac{\ell}{2} \quad (\ell = \text{overhang at } 41.5^\circ)$$

$$c = 2\ell \quad (\ell = \text{overhang at } 41.5^\circ)$$

$$G = Wc^3 \quad (W \text{ in g/cm}^2, c \text{ in cm, } G \text{ in g} \cdot \text{cm})$$

$$G = Wc^3 \quad (W \text{ in g/cm}^2, c \text{ in cm, } G \text{ in g} \cdot \text{cm})$$

From history. Colonial Williamsburg's tailor shop works today much as an eighteenth-century one did: sitting cross-legged on the bench, cutting from drafts, sewing every seam by hand and pressing with heavy irons heated in the fire. Its tailors serve long apprenticeships, as the trade always required.

WORKED EXAMPLES

Example 1. A wool twill strip overhangs 5.6 cm before drooping to 41.5°. The fabric weighs 280 g/m². Find the bending length and flexural rigidity.

Show solution

1. Bending length: $c = 5.6/2 = 2.8 \text{ cm}$; $c = 5.6/2 = 2.8 \text{ cm}$.
2. Weight per area: $280 \text{ g/m}^2 = 0.028 \text{ g/cm}^2$; $280 \text{ g/m}^2 = 0.028 \text{ g/cm}^2$.
3. $G = 0.028 \times 2.8^3 = 0.028 \times 21.95 = 0.61 \text{ g} \cdot \text{cm}$; $G = 0.028 \times 2.83 = 0.028 \times 21.95 = 0.61 \text{ g} \cdot \text{cm}$.

Answer: Bending length 2.8 cm; flexural rigidity about 0.61 g·cm.

Example 2. With fusible interfacing, the same strip overhangs 9.0 cm; the fused layers weigh 340 g/m². By what factor did stiffness increase?

Show solution

1. $c = 4.5 \text{ cm}$; $G = 0.034 \times 4.5^3 = 0.034 \times 91.1 = 3.10 \text{ g} \cdot \text{cm}$; $G = 0.034 \times 4.53 = 0.034 \times 91.1 = 3.10 \text{ g} \cdot \text{cm}$.
2. Factor: $3.10/0.61 \approx 5.1$.

Answer: About five times stiffer, though the bending length grew by only about 60%: the cube makes stiffness climb fast.

Example 3. A lapel's pad stitches are about 3/8 in long, in rows 3/8 in apart, over a lapel area of about 30 in². Estimate the number of stitches.

Show solution

1. Each stitch covers about $0.375 \times 0.375 = 0.14 \text{ in}^2$; $0.375 \times 0.375 = 0.14 \text{ in}^2$.
2. $30 \div 0.14 \approx 213$; $30 \div 0.14 \approx 213$.

Answer: Roughly 200 stitches for one lapel, about 400 for a pair, before the collar.

PRACTICE

1. **Easy** Who painted The Tailor, and about when?

Show answer

Giovanni Battista Moroni, about 1565–70.

2. **Easy** What does pad stitching do?

Show answer

It joins canvas to cloth while the layers are rolled, building a permanent curve into lapels and collars.

3. **Easy** Give one advantage each of fusible and sew-in interfacing.

Show answer

Fusible: fast and simple. Sew-in: keeps the fabric's drape and can be shaped.

4. **Medium** A strip overhangs 7.0 cm. Find its bending length.

Show answer

3.5 cm.

5. **Medium** Find G for $c = 3.0 \text{ cm}$ and $W = 0.025 \text{ g/cm}^2$.

Show answer

$0.025 \times 27 = 0.675 \text{ g} \cdot \text{cm}$; $0.025 \times 27 = 0.675 \text{ g} \cdot \text{cm}$

6. **Medium** Why should interfacing be equal to or lighter than the fashion fabric?

Show answer

A heavier interfacing overpowers the fabric, making it stiff, boardy and unnatural in drape.

7. **Medium** Convert 300 g/m^2 to g/cm^2 .

Show answer

0.030 g/cm^2 .

8. **Hard** If bending length doubles with no change in weight, by what factor does G change?

Show answer

$2^3 = 8$ times.

9. **Hard** Why does hair canvas suit a coat chest better than a stiff paper-like nonwoven?

Show answer

Hair canvas is springy and resilient, so the shaped chest recovers after being crushed and molds smoothly; a stiff nonwoven creases and cannot be shaped by steam.

10. **Hard** A fused sample's G is $2.4 \text{ g}\cdot\text{cm}$ and the plain fabric's $0.6 \text{ g}\cdot\text{cm}$. If the fused layers weigh 0.032 g/cm^2 , what was its bending length?

Show answer

$$c = \sqrt[3]{2.4/0.032} = \sqrt[3]{75} \approx 4.2 \text{ cm} = 3 \cdot 2.4/0.032$$

$\sqrt{\quad}$

$$= 3 \cdot 75$$

$\sqrt{\quad}$

$$\approx 4.2 \text{ cm}$$

11. **Challenge** Moroni painted a tailor with the dignity usually given to nobles. What does that suggest about how skilled work was valued, and how should a Christian view the skilled trades today?

Show answer

It suggests skilled craftsmen could earn honor and standing; Scripture honors skilled work (Exodus 35:35, Proverbs 22:29), so trades done well are a worthy calling, not a lesser one.

COMMON MISTAKES

- Fusing without a press cloth or enough time, so the interfacing bubbles after washing.
- Choosing interfacing heavier than the fabric. Support, do not overpower.
- Pad stitching through to the right side. Catch only a thread or two of the outer fabric.

Make it a game · Stiff or Soft? Collect ten fabrics and garment parts (a shirt collar, a cuff, a waistband, a T-shirt, a jacket lapel, felt, canvas, organza, flannel, a necktie). Players rank them by stiffness by feel. Then test five with the cantilever card. One point for each fabric placed within one position of its measured rank.

10.2 ALTERING STORE-BOUGHT CLOTHES

OBJECTIVES

- Tell the history of thrift in clothing, from hand-me-downs to the wartime Make Do and Mend campaign.
- Decide which alterations are worth doing, and hem, take in, let out and move buttons on real garments.
- Calculate alteration amounts per seam, hem allowances and the cost and time saved.

Warm-up. Find one garment in the house that nobody wears because of fit: too long, too loose, a button that pulls. Put it on (or have its owner do so) and describe exactly what is wrong in one sentence that names the garment, not the body.

WATCH

Learn How To Sew: Alterations - Taking In a Side Seam (Episode 17).

[Sewing Parts Online](#) · 9:42

<https://www.youtube.com/watch?v=ipiTJMD-GVU>

WHEN TO WATCH

Watch with your garment and seam ripper ready; pause after each step.

BACKUP VIDEO

How to Shorten Jeans-Keep the Original Factory Jean Hem - Pro results with Domestic Sewing Machine

[Notches Sewing](#) · 6:21

<https://www.youtube.com/watch?v=IfvUnjMaEpU>

Watch how the original jeans hem is saved and reattached when shortening.

KEY TERMS

alteration

Changing the size or shape of a finished garment to improve its fit.

original hem method

Shortening jeans or pants while keeping the factory hem, by folding up a tuck above it and stitching.

Make Do and Mend

A British government campaign and pamphlet of 1943 teaching families to repair, remake and care for clothing during wartime rationing.

taking in and letting out

Making a garment smaller or larger at its seams; letting out is possible only if the seam allowance is wide enough.

seam gauge

A small ruler with a sliding marker for measuring hems and allowances quickly.

worth-it test

Weighing the time and cost of an alteration against the value of the garment and how much it will be worn.

CORE IDEAS

The story. For most of history clothing was too costly to throw away. Garments were let out as children grew, taken in for younger siblings, turned inside out when the face wore, and finally cut down into children's clothes, quilts and rags. During World War II, with cloth and clothing rationed, Britain's Board of Trade published a 1943 pamphlet, *Make Do and Mend*, with practical advice on remaking and repairing clothes, and American home economists and extension agents taught the same thrift through the Depression and the war. Altering a garment so it fits is an old act of stewardship.

How they figured it out. Experienced sewers learned to read a garment before cutting anything: where the seams are, how much allowance they have, what is topstitched or serged, where the hem is and how it is finished. Easy alterations follow existing seams: shortening hems, taking in side seams, moving buttons. Harder ones disturb many seams at once: changing shoulders, collars or the rise of pants. The professional rule is to change as few seams as possible and to copy the original construction so the alteration is invisible.

The fabric science. Alterations must respect the fabric. Letting out a seam reveals fabric that was hidden inside, which may be a different shade if the garment has faded, and old stitch holes may show in firm fabrics. Taking in a seam reduces ease, so measure what ease the wearer needs (Unit 8). Hems in jeans are felled and topstitched with heavy thread; keeping the original hem preserves the look. As with fitting, a circumference change is shared among the seam edges: taking 2 in out of a shirt's chest at two side seams means $\frac{1}{2}$ in off each edge.

The worth-it test. Not every garment deserves an alteration. Ask: Is the fabric good and the garment otherwise sound? Will the alteration make it truly wearable? Will the person wear it often? Does the time and cost compare well with buying another? A well-made wool coat almost always passes; a worn, cheap T-shirt rarely does, except as practice.

The studio lab. You will alter at least two real garments for your family: one hem (with the original-hem method on jeans if you can) and one seam change or button move, measuring before and after, logging time and working out what a tailor would have charged.

PICTURE STUDY



The Young Seamstress, Jozef Israëls, 19th century · Oil on canvas · Image from Wikimedia Commons (Google Art Project), public domain
Image: [Wikimedia Commons](#), public domain

Jozef Israëls, a Dutch painter of fishing villages and ordinary homes, painted a young woman absorbed in her sewing by a window. In such homes, garments were made over and over: let out, taken in, mended and handed down.

Look closely

- Find the garment in her hands. Is it new work or repair?
- Look at the window light. Why sew there?
- Look at the room. What does it tell you about the family's means?
- Look at her posture and face. How does the painter make quiet work feel important?

Talk about it

1. In a household like this, how many times might one coat be altered before it was finally cut into rags?
2. What alterations would she most likely be making, and why?
3. How does this painting connect to the idea of stewardship?

Safety first. Use the seam ripper away from your body and slip it under single stitches, not through fabric. Try garments on carefully when pinned, with pins pointing away from the body, and remove them before taking the garment off. Alterations on other people's clothes are fitted by a parent (the father for a son or the mother for a daughter).

Two Real Alterations for the Family

Question: Can you make two store-bought garments fit their owners invisibly, and is it worth the time? You will alter, measure, log and cost two garments.

You will need

- Two garments needing alteration (jeans or pants to hem; a shirt or skirt to take in, or buttons to move)
- A seam ripper, a seam gauge, tailor's chalk, matching thread (jeans thread for denim), pins, the iron
- A notebook page for each garment

Steps

1. **Hypothesis.** Estimate the time each alteration will take and what a tailor would charge.
2. Fit each garment on its owner (with a parent fitting as appropriate). Pin and mark the change. Measure and record before.
3. Inspect the construction: seam types, finishes, topstitching. Plan to copy it.
4. Alter the first garment (hem). On jeans, use the original-hem method; on dress pants, make a blind hem.
5. Alter the second garment (take in or let out a seam, or move buttons), unpicking only what you must.
6. Press, try on again, and measure after. Log your time and materials.
7. **Conclude.** Was each alteration invisible? Compare your time and cost with a tailor's price.
8. **Repeat round.** Ask the owners to wear the garments for a week and report. Adjust anything that is not right.

Tips

- Photograph seams before unpicking so you can copy the original construction.
- Use jeans needles and heavy thread on denim hems; denim layers are thick at the seams. Walk the wheel by hand over bulky spots.
- Mark changes on the inside with chalk, never with a pen.

Check your work

- ☐ I fitted, marked and measured each garment carefully and modestly.
- ☐ My alterations copy the original construction and are neatly pressed.
- ☐ I logged time and cost and compared them with a tailor's price.

LAB NOTEBOOK

1. Draw before-and-after sketches of each alteration with measurements.
2. Write your worth-it test results for both garments.
3. Record each owner's verdict after a week.

KEY FORMULAS

$$\text{change per seam edge} = \frac{\text{total change}}{\text{number of seam edges}}$$

$$\text{change per seam edge} = \frac{\text{number of seam edges} \times \text{total change}}{\text{total change}}$$

$$\text{tuck depth (original hem)} = \frac{\text{amount to shorten}}{2}$$

$$\text{tuck depth (original hem)} = 2 \times \text{amount to shorten}$$

From history. The Make Do and Mend pamphlet even featured a cartoon character, Mrs. Sew-and-Sew, who encouraged readers to turn old garments into new ones. Classes in mending and remaking were held in community centers across Britain during the war.

WORKED EXAMPLES

Example 1. Jeans must be shortened 2 in using the original-hem method. How deep a tuck is folded above the hem, and where is the stitching line?

Show solution

1. A folded tuck takes up twice its depth: $2 \text{ in} \div 2 = 1 \text{ in}$ $2 \text{ in} \div 2 = 1 \text{ in}$.
2. Fold the hem up so 1 in of leg is folded under the hem's top edge, and stitch just below the hem's edge (close to the hem), then trim and finish the excess and press it toward the leg.

Answer: A 1-in-deep tuck removes 2 in of length while keeping the factory hem.

Example 2. A shirt's chest is 4 in too loose. You will take in only the two side seams, and the sleeves will be taken in to match. How much comes off each edge?

Show solution

1. Two side seams, each with a front and back edge: 4 edges.
2. $4 \text{ in} \div 4 = 1 \text{ in}$ $4 \text{ in} \div 4 = 1 \text{ in}$, tapering to nothing at the hem or continuing into the sleeve seam.

Answer: 1 in from each edge, tapering smoothly; the new seam line runs 1 in inside the old one.

Example 3. A tailor charges \$18 to hem pants and \$24 to take in a shirt. You did both in 1 hr 40 min using \$0.50 of thread. What did you save, and what is that per hour of your work?

Show solution

1. Saved: $18 + 24 - 0.50 = 41.50$ $18 + 24 - 0.50 = 41.50$.
2. Per hour: $41.50 \div 1.67 \text{ h} \approx 24.85 \text{ per hour}$ $41.50 \div 1.67 \text{ h} \approx 24.85 \text{ per hour}$.

Answer: You saved \$41.50, roughly \$25 for each hour of your work.

PRACTICE

1. Easy What was Make Do and Mend, and when was it published?

Show answer

A British Board of Trade wartime pamphlet and campaign on repairing and remaking clothes, 1943.

2. Easy Name three easy alterations and one hard one.

Show answer

Easy: hems, taking in side seams, moving buttons. Hard: shoulders, collars or pants rise.

3. Easy What tool measures hems quickly?

Show answer

A seam gauge.

4. Medium Shorten pants 3 in by the original-hem method. Tuck depth?

Show answer

1½ in.

5. Medium Take 3 in out of a skirt waist at two side seams. Per edge?

Show answer

¾ in.

6. Medium Why might letting out a seam leave a visible line?

Show answer

The hidden fabric may be less faded, and old stitch holes can show in firm fabrics.

7. **Medium** List three questions in the worth-it test.

Show answer

Is the fabric good and garment sound? Will it truly fit and be worn often? Does the time and cost compare well with buying another?

8. **Hard** A seam has a $\frac{5}{8}$ -in allowance with $\frac{3}{8}$ in usable after finishing. How much can the garment's circumference be let out at two side seams?

Show answer

$\frac{3}{8}$ in per edge $\times$ 4 edges = $1\frac{1}{2}$ in.

9. **Hard** A tailor would charge \$30; your time is 2 h and materials \$1. Is it worth it at an imagined wage of \$12/h? Explain.

Show answer

Your time valued at \$24 plus \$1 = \$25, less than \$30, so yes; and you gain skill besides.

10. **Hard** Why change as few seams as possible in an alteration?

Show answer

Each opened seam risks fraying, shading and mismatched topstitching; fewer changes keep the alteration invisible and the garment strong.

11. **Challenge** A grandmother's wool coat fits a granddaughter except that it is $1\frac{1}{2}$ in long in the sleeves and 2 in loose at the waist. Plan the alteration, in order, with the amounts.

Show answer

Shorten sleeves from the cuff (open lining, take up $1\frac{1}{2}$ in, re-hem, reattach lining); take in the waist at the side or back seams by $\frac{1}{2}$ in per edge (4 edges), tapering; press and check lining ease. Credit for a sensible order and correct arithmetic.

COMMON MISTAKES

- Cutting off extra length before trying on and marking. Measure twice, cut once, and only after pinning on the wearer.
- Taking in only one side of a garment. Share the change across seams to keep it balanced.
- Using all-purpose thread for denim topstitching. Match the original thread weight and color.

Make it a game · Tailor's Quote. A parent shows a garment with a fit problem. Players secretly write the alteration needed, the seams to open and the minutes it will take. Points for the right alteration, the right seams and the closest time estimate. Then do the fastest one for real.

10.3 MENDING: DORCAS AND THE COATS SHE MADE

OBJECTIVES

- Choose the right mend for damage: darning, patching, reinforcing, restitching a seam or replacing a closure.
- Darn a hole, patch a garment invisibly or visibly, and preshrink patches.
- Calculate patch sizes, darning grids and the value of mending.

Warm-up. Gather the family's mending pile (or ask everyone for one item that needs repair). Sort it into holes, tears, seam splits, worn spots and lost buttons. Which is most common?

WATCH

How to Repair a Hole in a Sock with Darning

[Professor Pincushion](#) · 4:58

https://www.youtube.com/watch?v=yi_J8YeQkww

WHEN TO WATCH

Watch with a sock, darning egg, needle and yarn in hand; darn along with the video.

BACKUP VIDEO

How to Patch Jeans Without a Sewing Machine

[WonderFil Specialty Threads](#) · 3:15

<https://www.youtube.com/watch?v=XweldFH-IOI>

Watch a hand-sewn patch on jeans, then patch your own.

KEY TERMS

darning

Reweaving a hole with a needle and thread or yarn: first lengthwise threads (warp), then crosswise threads woven through them (weft).

reinforcement

Extra stitching or a backing added to a weak area before it fails, such as knees, elbows and pocket corners.

visible mending

Repairs made deliberately decorative with contrasting thread or patches.

patch

A piece of fabric sewn over or behind a hole or worn area.

invisible mending

Repairs made with matching threads or fabric so they are hard to see.

preshrinking

Washing or steaming patch fabric before use so it will not shrink and pull at the garment.

CORE IDEAS

The story. In Joppa there lived a disciple named Dorcas (Tabitha), “full of good works and almsdeeds.” When she died, the believers sent for Peter, and when he came, “all the widows stood by him weeping, and shewing the coats and garments which Dorcas made, while she was with them.” Her needle had clothed the poor of her town. Peter prayed, and God raised her to life. For centuries afterward, church sewing circles called themselves Dorcas societies and met to make and mend clothing for those in need.

How they figured it out. Households mended constantly because cloth was precious. Darning, reweaving a hole with thread, was taught to children, and every sewing basket held a wooden darning egg or mushroom to stretch the work. Patches covered larger holes, set in from behind for invisibility or on top for strength. Knees, elbows and pocket corners were reinforced before they failed. The same principle Jesus taught, never sew unshrunk cloth to an old garment (Mark 2:21), guided every patch.

The fabric science. A darn rebuilds fabric structure: lengthwise threads across the hole form a warp, and crosswise threads woven over and under them form a weft, anchored well into the sound fabric around the hole, where the stress is shared. Use a thread or yarn of similar fiber and weight: too strong, and the darn tears the fabric beside it; too weak, and it fails first. A patch should be the

same fiber and weight (or a little lighter), preshrunk, cut on the same grain, and extend at least ½ to 1 in beyond the damaged area on every side, so stitches land in sound fabric.

Mending as stewardship. A mended garment is not a lesser garment. Repairs that are careful, even beautiful, are a sign that someone valued it. Mending also connects to giving: a well-mended coat can be given away, as Dorcas gave, and a family's mending skill clothes many people over years.

The studio lab. You will repair at least three real items from the family mending pile with three different techniques: a darn (sock or sweater), a patch (jeans knee or elbow) and a seam or closure repair, logging each with before-and-after photos, time and the value of the garment saved.

PICTURE STUDY



The Net Menders (Die Netzflickerinnen), Max Liebermann, 1887–89 · Oil on canvas · Hamburger Kunsthalle, Hamburg
Image: [Wikimedia Commons](#), public domain

Max Liebermann painted the wives and daughters of Dutch fishermen mending the great nets on the windy dunes. Mending nets, like mending clothes, was patient, constant work on which a family's living depended.

Look closely

- Find a mender's hands. How is she holding the net and the needle?
- Look at the net spread over the dunes. How large is it?
- Notice the wind and the weather. How does Liebermann show it?
- Count the menders. Is this solitary or shared work?

Talk about it

1. A net with one broken mesh soon has many. How is that true of clothing too?
2. What would happen to a fishing family if no one mended the nets?
3. How is net mending like darning a sock?

Safety first. Keep darning needles in the pincushion and count them out and back in. Use a darning egg or mushroom, never your hand, inside a sock while darning. Iron-on patches are applied with a press cloth and an upright iron, unplugged afterward.

STUDIO LAB

Three Mends from the Family Pile

Question: Which mending method best restores each kind of damage, and how much value does mending save? You will repair three real items with three different techniques.

You will need

- Three items needing repair: a sock or sweater with a hole, jeans or pants with a worn knee or tear, and a garment with a split seam or missing button
- A darning egg or mushroom, a darning needle, matching yarn or thread, patch fabric (preshrunk), pins, a seam ripper and the machine
- A camera for before-and-after photos

Steps

1. **Hypothesis.** Predict which mend will take longest and which will be least visible.
2. Photograph and measure each damage. Choose the method for each and write why.
3. **Darn.** Stretch the sock over the darning egg, trim loose threads, lay warp threads $\frac{1}{2}$ in beyond the hole, and weave the weft through them. Keep the tension even and the darn flat.
4. **Patch.** Calculate the patch size, preshrink and cut it on the garment's grain, and set it from the back (or on top for strength), stitching by hand or machine into sound fabric.
5. **Seam or closure.** Restitch a split seam $\frac{1}{2}$ in past the break at each end, or sew on a matching button with a shank.
6. Photograph each mend. Log time, materials and the replacement value of each item.
7. **Conclude.** Which method worked best for which damage? How much value did your mending save per hour?
8. **Repeat round (service).** Mend one more item for someone outside your family, a neighbor or a church clothing closet, and record it.

Tips

- Darn from the wrong side for invisibility; leave yarn tails woven into sound fabric rather than knotted.
- Round the corners of patches slightly; square corners lift and fray.
- Wash mended items once and check that the repair holds before returning or giving them.

Check your work

- ☐ I repaired three items with three different methods, choosing each for the damage.
- ☐ My mends are flat, secure and anchored in sound fabric.
- ☐ I logged time and value saved, and mended one item for someone else.

LAB NOTEBOOK

1. Draw a darn in progress: hole, warp threads, weft weaving.
2. Tape in before-and-after photos of each mend with notes.
3. Write a short history of Dorcas societies and one way your family could serve through mending.

KEY FORMULAS

$$\begin{aligned}\text{patch size} &= \text{damage size} + 2 \times \text{margin} + 2 \times \text{turn-under} \\ \text{patch size} &= \text{damage size} + 2 \times \text{margin} + 2 \times \text{turn-under} \\ \text{darning threads} &= \text{darn width} \times \text{threads per inch} \\ \text{darning threads} &= \text{darn width} \times \text{threads per inch}\end{aligned}$$

From history. Dorcas societies spread through English-speaking churches in the 1800s, meeting weekly to sew and mend clothing for the poor, missionaries' families and orphanages. Many church clothing closets today carry on the same work.

WORKED EXAMPLES

Example 1. A worn knee area is $2\frac{1}{2} \times 3$ in. You want 1 in of sound fabric beyond the damage on every side and a $\frac{1}{4}$ -in turn-under. What size do you cut the patch?

Show solution

1. Width: $2.5 + 2(1) + 2(0.25) = 5$ in $2.5 + 2(1) + 2(0.25) = 5$ in.
2. Height: $3 + 2(1) + 2(0.25) = 5.5$ in $3 + 2(1) + 2(0.25) = 5.5$ in.

Answer: Cut a $5 \times 5\frac{1}{2}$ in patch.

Example 2. A sock hole is $\frac{3}{4}$ in wide. The darn extends $\frac{1}{2}$ in beyond the hole on each side, and you lay 16 warp threads per inch. How many warp passes, and how much yarn at about 2 in per pass?

Show solution

1. Darn width: $0.75 + 2(0.5) = 1.75$ in $0.75 + 2(0.5) = 1.75$ in.
2. Passes: $1.75 \times 16 = 28$ $1.75 \times 16 = 28$.
3. Yarn: $28 \times 2 = 56$ in $28 \times 2 = 56$ in, about the same again for the weft.

Answer: About 28 warp passes and roughly 3 yd of yarn in all.

Example 3. Three mended items would cost \$45, \$30 and \$12 to replace. Mending took $2\frac{1}{2}$ hours and \$2 of materials. Find the value saved per hour.

Show solution

1. Saved: $45 + 30 + 12 - 2 = 85$ $45 + 30 + 12 - 2 = 85$.
2. Per hour: $85 \div 2.5 = 34$ $85 \div 2.5 = 34$.

Answer: About \$34 of value saved per hour of mending.

PRACTICE

1. **Easy** What did the widows show Peter?

Show answer

The coats and garments which Dorcas made.

2. **Easy** Describe the two stages of a darn.

Show answer

Lay lengthwise (warp) threads across the hole, then weave crosswise (weft) threads over and under them.

3. **Easy** Why preshrink patch fabric?

Show answer

So it does not shrink later, pull at the garment and tear it (Mark 2:21).

4. **Medium** Damage 2×2 in, 1-in margin, $\frac{1}{4}$ -in turn-under. Patch size?

Show answer

$4\frac{1}{2} \times 4\frac{1}{2}$ in.

5. **Medium** A darn 2 in wide at 12 threads per inch needs how many warp passes?

Show answer

24.

6. **Medium** Why should a darning yarn not be much stronger than the fabric?

Show answer

The fabric around the darn would tear first, making a bigger hole.

7. **Medium** Name three places to reinforce before they fail.

Show answer

Knees, elbows, pocket corners (also crotch seams, sock heels).

8. **Hard** A patch is cut on the bias while the jeans are on the straight grain. What will happen in wear and washing?

Show answer

The bias patch stretches and distorts differently from the jeans, puckering and pulling; cut patches on the same grain.

9. **Hard** Mending 5 items worth \$120 took 4 h and \$3. Value per hour?

Show answer

$117/4 = \$29.25$ 117/4 = \$29.25 per hour.

10. **Hard** When would you choose visible mending over invisible mending?

Show answer

When matching fabric or thread is unavailable, on casual or work clothes, or when a decorative repair is wanted; invisible for dress clothes and where a repair should not show.

11. **Challenge** Plan a Dorcas project: mend and prepare five garments to give away. Describe the mending, the checks before giving, and how you would present them.

Show answer

A good plan sorts usable garments, mends each soundly (darns, patches, buttons, seams), washes and presses, checks for stains and odors, labels sizes, and gives them through a church closet or shelter with dignity.

COMMON MISTAKES

- Darning only to the edge of the hole. Extend into sound fabric so the stress is shared.
- Using an unshrunk patch. It will shrink and pucker the garment.
- Pulling darning threads tight, which puckers the fabric. Keep tension even and relaxed.

Make it a game • Mend Match. A parent lays out damaged items and cards naming mending methods (darn, patch from back, patch on top, restitch seam, replace button, reinforce). Players race to match each item with the best method and defend the choice in one sentence. Points for each match the parent agrees with.

Scripture. “Then Peter arose and went with them. When he was come, they brought him into the upper chamber: and all the widows stood by him weeping, and shewing the coats and garments which Dorcas made, while she was with them.” (Acts 9:39, KJV)

The widows remembered Dorcas by the garments she had sewn for them. Making and mending clothing for others is a ministry Scripture records with honor.

10.4 CARE, COST PER WEAR AND MAKE OR BUY

OBJECTIVES

- Plan the care of a wardrobe by fiber, including washing, drying, storage and pest prevention.
- Calculate cost per wear and compare making, buying and mending honestly, including time.
- Audit a wardrobe and write a care and repair plan.

Warm-up. Choose your most-worn garment and your least-worn garment. Estimate what each cost and how many times you have worn it. Which has given better value?

WATCH

How to Wash A Wool Sweater, With Rajiv Surendra | Life Skills With Rajiv

HGTV Home • 15:02

<https://www.youtube.com/watch?v=d5a48yClhqs>

WHEN TO WATCH

After “The fabric science.” Watch each step of hand washing a wool sweater and connect it to the felting rules of Unit 2.

BACKUP VIDEO

How to Hand Wash a Wool Sweater

Woolmark • 1:35

<https://www.youtube.com/watch?v=28MW0bGgcUA>

A short summary of hand washing wool, for the laundry-room wall.

KEY TERMS

cost per wear

A garment's total cost (price plus care and repairs) divided by the number of times it is worn.

opportunity cost

The value of what you give up, such as the time spent sewing instead of something else.

clothes moths and carpet beetles

Insects whose larvae eat keratin (wool, silk, fur), especially when soiled; clean storage and inspection prevent damage.

make-or-buy decision

Comparing the full cost, quality and fit of sewing a garment with buying a similar one.

wardrobe audit

A careful inventory of clothing: what is worn, what needs care or repair, and what is missing.

stewardship

Caring well for what God has entrusted to us, including the things we wear.

CORE IDEAS

The story. The capable woman of Proverbs “maketh fine linen, and selleth it; and delivereth girdles unto the merchant.” She knew the value of her work, made what was worth making, bought and sold wisely, and cared for her household's clothing so that none of them feared the cold. In the early 1900s, America's Cooperative Extension Service, created by the Smith-Lever Act of 1914, sent home economics agents into rural communities to teach clothing construction, care and budgeting. Through the Depression they taught families to remake, mend and plan, and 4-H clothing clubs taught young people to sew, care for and judge garments.

How they figured it out. Extension economists and home economists taught families to think in terms of value over a garment's life: a well-made garment worn often and cared for costs less per wearing than a cheap one worn a few times. They taught record-keeping: a clothing inventory, a budget, and a plan for what to buy, make or remake each season. The same arithmetic still helps: cost per wear, the full cost of making (including time), and the savings from care and repair.

The fabric science. Care follows chemistry. Wash wool cool and gently to prevent felting; keep chlorine bleach away from wool, silk and spandex; dry cotton and linen thoroughly to prevent mildew; air synthetics so oily odors do not build up; store protein fibers clean, because moth and beetle larvae seek soiled keratin; fold heavy knits rather than hanging them so they do not stretch; and let

shoes, coats and sweaters rest between wearings so fibers recover. Reading and following care labels (Unit 6) is the simplest way to double a garment's life.

Make or buy, honestly. Sewing is not always cheaper than buying: mass-produced basics can cost less than their fabric alone. Sewing is worth it when it gives better fit, better quality, garments that are hard to buy (modest, durable, or the right size), the satisfaction of skill, or a gift for someone else, and mending is almost always worth it. An honest comparison includes materials, time, quality and how long each garment will last.

The studio lab. You will audit your own wardrobe (or a section of it), calculate cost per wear for five garments, compare the make-or-buy cost of your Unit 9 pajama pants, and write a care and repair plan for the year ahead.

PICTURE STUDY



Three Old Seamstresses (Tre gamle syersker), Anna Ancher, 1920 · Oil on canvas · Image from Wikimedia Commons, public domain
Image: [Wikimedia Commons](#), public domain

Anna Ancher spent her life painting the people of Skagen, a fishing town at the northern tip of Denmark. Here three elderly women sit sewing together, a lifetime of making and mending in their hands.

Look closely

- Find each woman's work. Is it sewing, mending or knitting?
- Look at their tools and the light. Where do they sit, and why?
- Look at their faces. What does their companionship add to the work?
- Look at their clothing. How might it have been cared for over many years?

Talk about it

1. How many garments might these women have made and mended in their lives?
2. What does the painting suggest about sewing as shared, lifelong work?
3. What could you learn from someone who has sewn for sixty years?

Safety first. Moth prevention uses cleaning, airing, freezing and sealed storage; mothballs (naphthalene or paradichlorobenzene) are harmful if inhaled or swallowed, are not used in this lab, and if a family uses them they are kept sealed and away from children and pets. Keep laundry products labeled and out of reach of young children.

STUDIO LAB

Wardrobe Audit and Care Plan

Question: Which garments give the best value, and what care and repair would make the rest last longer? You will audit a wardrobe, calculate cost per wear and write a plan.

You will need

- Your own clothes (or one season's worth), a notebook or spreadsheet, a tape measure
- Your Unit 9 cost sheets and construction logs
- Care labels and the care-symbol chart from Unit 6

Steps

1. **Hypothesis.** Predict which of your garments has the lowest and the highest cost per wear.
2. List every garment with its fiber, construction quality (seams, finishes), condition and care label.
3. Choose five garments, estimate price, care costs and wears so far and to come, and calculate cost per wear.
4. Do the make-or-buy comparison for your pajama pants at two values of your time.
5. Mark every garment that needs care (washing method change, de-pilling, storage) or repair (mending, buttons, hems).
6. Write a one-page care and repair plan: what you will fix this month, how you will store each fiber, and what you need to sew or buy, with a budget.
7. **Conclude.** What did the numbers teach you about value? What will you change?
8. **Repeat round.** Carry out the first three repairs on your plan and update your cost-per-wear numbers.

Tips

- Be honest about wears: a garment worn twice in a year is telling you something.
- Group by fiber for storage: wool and silk clean, folded and sealed; cotton and linen dry and aired.
- Plan your capstone to fill a real gap in your wardrobe or someone else's.

Check your work

- ☐ I audited a wardrobe with fiber, condition and care for every garment.
- ☐ I calculated cost per wear for five garments and a fair make-or-buy comparison.
- ☐ I wrote a practical care and repair plan and began it.

LAB NOTEBOOK

1. Paste your wardrobe audit table.
2. Graph cost per wear for your five garments.
3. Write your care and repair plan and your capstone idea.

KEY FORMULAS

$$\text{cost per wear} = \frac{\text{price} + \text{care and repair costs}}{\text{number of wears}}$$

$$\text{cost per wear} = \text{number of wears} \div \text{price} + \text{care and repair costs}$$

$$\text{make cost} = \text{materials} + \text{hours} \times \text{value of an hour}$$

$$\text{make cost} = \text{materials} + \text{hours} \times \text{value of an hour}$$

From history. 4-H clothing clubs, begun in the 1910s, held clothing judging and “dress revue” contests at county and state fairs in which young people modeled garments they had made and explained their choices of fabric, construction and cost. Many 4-H clubs still hold them.

WORKED EXAMPLES

Example 1. Coat A costs \$180, lasts 8 winters worn 60 times each, with \$40 of dry cleaning and repairs. Coat B costs \$60 and lasts 2 winters worn 60 times each with \$5 of care. Compare cost per wear.

Show solution

1. A: $\frac{180 + 40}{8 \times 60} = \frac{220}{480} \approx 0.468 \times 60 = 0.46$.

2. B: $\frac{60 + 5}{2 \times 60} = \frac{65}{120} \approx 0.542 \times 60 = 0.54$.

Answer: Coat A costs about 46 cents per wear and coat B about 54 cents: the dearer, better coat is cheaper in use.

Example 2. Your pajama pants cost \$22.35 in materials and took 5 hours. A similar store pair costs \$24. If you value your time at \$0 (a hobby) or at \$8 per hour, what is the make cost each way?

Show solution

1. At \$0: $22.35 + 5 \times 0 = 22.35$.

2. At \$8: $22.35 + 5 \times 8 = 62.35$.

Answer: \$22.35 as a hobby, \$62.35 counting time at \$8 an hour. The second pair, sewn faster, will cost less; and fit, fabric and skill are gains a price tag does not show.

Example 3. A \$40 sweater worn 20 times a year lasts 2 years if machine-washed hot and 6 years if hand-washed cool (adding about \$3 per year of wool wash). Find each cost per wear.

Show solution

1. Hot wash: $\frac{40}{2 \times 20} = 1.002 \times 20 = 1.00$.

2. Hand wash: $\frac{40 + 6 \times 3}{6 \times 20} = \frac{58}{120} \approx 0.486 \times 20 = 0.48$.

Answer: \$1.00 against about \$0.48 per wear: careful care roughly halves the cost.

PRACTICE

1. Easy Define cost per wear.

Show answer

Total cost (price, care and repairs) divided by the number of times worn.

2. Easy What law created the Cooperative Extension Service, and when?

Show answer

The Smith-Lever Act, 1914.

3. Easy Why store wool clean?

Show answer

Moth and beetle larvae are drawn to soiled keratin.

4. Medium A \$30 shirt worn 50 times with \$5 of care. Cost per wear?

Show answer

70 cents.

5. Medium Materials \$35, 6 hours at \$10/hour. Make cost?

Show answer

\$95.

6. **Medium** Name two reasons to sew a garment even if buying is cheaper.

Show answer

Better fit, better quality or fabric, modesty or availability, skill, a gift for someone else (any two).

7. **Medium** Why fold heavy sweaters instead of hanging them?

Show answer

Their weight stretches the shoulders and length on a hanger.

8. **Hard** Jeans at \$25 last 1 year worn 100 times; jeans at \$70 last 4 years worn 100 times a year, with one \$15 repair. Compare cost per wear.

Show answer

$\$0.25$ vs. $85/400 \approx \$0.2185/400 \approx \$0.21$: the better jeans are cheaper per wear.

9. **Hard** A mended coat adds 3 years of 50 wears for \$12 of repairs. What is the cost per added wear?

Show answer

$12/150 = \$0.08$

10. **Hard** Explain opportunity cost in a make-or-buy decision, and why it is not the whole story.

Show answer

Time spent sewing could be used otherwise, so it has value; but sewing also produces skill, fit, quality and gifts, and may be restful, so time is not purely a cost.

11. **Challenge** Proverbs 31:24 says the capable woman makes fine linen and sells it. What does that suggest about valuing handwork, pricing it and stewardship?

Show answer

Her skill had market value; she priced and sold it wisely and supplied merchants. Handwork deserves fair value, should be done well enough to sell, and a household's skills can provide for others as well as itself.

COMMON MISTAKES

- Judging value by price alone. Use cost per wear.
- Leaving out time in make-or-buy comparisons, or counting only time. Count materials, time, quality and life.
- Storing worn wool in a closet over summer. Clean and seal it first.

Make it a game · Cost-per-Wear Showdown. Each player picks three garments from the family and writes down price and wears (estimated by the owner). Everyone calculates cost per wear. The lowest number wins, but the winner must name the care habit that made the garment last.

Scripture. “She maketh fine linen, and selleth it; and delivereth girdles unto the merchant.” (Proverbs 31:24, KJV)

The capable woman's handwork was good enough to sell. Valuing work fairly, and caring for what we own, are part of the stewardship Scripture praises.

10.5 THE CAPSTONE GARMENT

OBJECTIVES

- Write a design brief and choose a modest, useful garment, fabric and pattern for a real person and purpose.
- Adapt or draft the pattern, fit a muslin, and plan the order of construction and budget.
- Construct and finish the garment with a complete construction log, cost analysis and evaluation.

Warm-up. Look back through your lab notebook from the whole year. List the five skills you are proudest of and the two you most want to improve. Which garment could use all five and practice the two?

WATCH

How to make a Savile Row Suit (Part 1) – with Anderson & Sheppard | FASHION AS DESIGN

The Museum of Modern Art · 9:41

<https://www.youtube.com/watch?v=Vfw9zsHLU2s>

WHEN TO WATCH

Watch how a bespoke tailoring house moves from measuring to pattern to cutting, and compare each stage with your capstone plan.

KEY TERMS

design brief

A short written plan stating who the garment is for, its purpose, requirements (fit, modesty, care, budget) and success criteria.

critical path

The sequence of steps that must happen in order and determines the shortest time to finish.

evaluation

An honest judgment of the finished garment against the design brief: what works, what does not, what to change.

construction log

A dated record of every step, decision, problem and fix in making a garment.

budget

A planned limit on spending, with an itemized estimate checked against actual costs.

portfolio

The collected evidence of the project: brief, sketches, pattern, muslin notes, log, costs, photos and evaluation.

CORE IDEAS

The story. Georg Friedrich Kersting painted a young woman in Germany, about 1817, embroidering at a window in a plain, orderly room, intent on her work. The picture is quiet, but it captures what this whole course has aimed at: careful, patient making in a well-ordered life. Your capstone joins a long tradition of finished work: the tabernacle curtains, Hannah's little coat, Dorcas's garments for the widows, the coats of Moroni's tailor and Colonial Williamsburg's shop. "Put on therefore ... kindness," Paul wrote; a garment made well and given or worn with gratitude is a small picture of that grace.

How they figured it out. Every good maker works the same way: understand the person and the purpose, plan, test, build, check and improve. Professional tailors and costume shops write the brief, sketch, choose fabric, make a pattern, fit a toile, construct, fit again and finish. Your capstone follows the same path, with your lab notebook as the construction log.

The fabric science (choosing well). Use everything you know. Choose fiber for the use: cotton or linen for warmth-weather comfort, wool for warmth and resilience, a cotton/polyester blend for easy care, a little spandex for movement. Choose structure: a firm woven for tailored shapes, a knit for stretch garments, a twill for wear. Check weight in g/m², preshrink, read the care needs, and make sure the pattern's ease, your measurements and the fabric's stretch agree. A garment is only as good as the match between design, fabric and fit.

Good capstone choices. A button-front shirt; a lined vest with welt pockets; a skirt with a zipper and waistband; trousers with a fly front; a jumper or pinafore over a blouse; a lined jacket; a set of matching garments for younger siblings; or a garment for someone

in need. Every capstone is modest and practical, and the brief, not the difficulty alone, defines success.

The studio lab. This lesson launches the capstone: brief, design, pattern, muslin and plan in the first sessions, then construction over the following weeks, ending in a finished garment, a full portfolio and a presentation to your family.

PICTURE STUDY



The Embroiderer (Woman Embroidering), Georg Friedrich Kersting, c. 1817 · Oil on canvas · National Museum in Warsaw
Image: [Wikimedia Commons](#), public domain

Kersting painted quiet, orderly rooms where people read, wrote or worked by the window. Here a young woman sits embroidering, her back half turned to us, absorbed in her stitches. Everything in the room is plain and in its place.

Look closely

- Find her hoop or frame and her needle. What is she making?
- Look at the window and the light on her work.
- Look at the room's furniture and walls. What mood does the order create?
- Notice that we do not see her face. Why might Kersting paint her this way?

Talk about it

1. How is her focused work like the final weeks of your capstone?
2. What habits of an orderly workspace would help you finish well?
3. If you could ask her one question about her work, what would it be?

Safety first. All the year's tool rules apply: a parent has signed off every tool you use; fingers stay an inch from the needle; pins come out before the presser foot; rotary blades are closed when set down; irons rest upright and are unplugged at the end; the needle-and-pin count closes every session. Fittings on a person are done modestly by a parent (the father for a son or the mother for a daughter).

STUDIO LAB

Design, Fit and Build Your Capstone Garment

Question: Can you plan and build a modest, well-made garment that meets a written design brief for a real person and purpose? You will design, pattern, fit, construct and evaluate a capstone garment, with a full log and cost analysis.

You will need

- A pattern (commercial, adapted, or drafted from your Unit 8 work) suited to the garment
- Muslin for the test garment, fashion fabric, lining, interfacing and notions as the pattern requires, prewashed
- All your tools, your measurement card, your lab notebook and a camera

Steps

1. **Brief.** Write a one-page design brief: who, purpose, requirements (fit, modesty, care, budget, deadline) and three measurable success criteria. Have a parent approve it.
2. **Design.** Sketch the garment front and back, choose fabric with reasons (fiber, weave, weight, care), and make a fabric and notions list.
3. **Budget and schedule.** Calculate yardage and cost, and estimate time for each stage. Set a finish date.
4. **Pattern and muslin.** Adapt or draft the pattern, sew a muslin, fit it, and transfer the changes.
5. **Cut and construct.** Cut the fashion fabric on grain, interface, and construct in a planned order, pressing every seam. Log each step, its time and any unpicking.
6. **Fit again and finish.** Fit before hems and closures. Finish buttonholes, hems and pressing.
7. **Evaluate.** Check each success criterion. Calculate actual cost, budget variance and projected cost per wear. Write what you would change.
8. **Present.** Wear or give the garment, photograph it, and present your portfolio to your family: brief, sketches, pattern, muslin notes, log, costs and evaluation.

Tips

- Choose a garment one step beyond what you have done, not three.
- Log as you go; reconstructing a log from memory never works.
- If something goes wrong, record it, fix it and keep going. Every finished garment has a story of things that went wrong.

Check your work

- ☐ My brief, design, budget and schedule were written and approved before I cut.
- ☐ My muslin was fitted and my pattern corrected; the finished garment fits as planned.
- ☐ My construction log, cost analysis and honest evaluation are complete.

LAB NOTEBOOK

1. Write and tape in your design brief and sketches.
2. Keep the full construction log with dates, times and fixes.
3. Finish with your evaluation, cost analysis and a photo of the garment worn or given.

KEY FORMULAS

$$\begin{aligned}\text{total cost} &= \text{fabric} + \text{lining} + \text{interfacing} + \text{notions} + \text{thread} \\ \text{total cost} &= \text{fabric} + \text{lining} + \text{interfacing} + \text{notions} + \text{thread} \\ \text{budget variance} &= \text{actual cost} - \text{budgeted cost} \\ \text{budget variance} &= \text{actual cost} - \text{budgeted cost} \\ \text{projected cost per wear} &= \frac{\text{total cost}}{\text{expected wears}} \\ \text{projected cost per wear} &= \text{expected wear} \div \text{total cost}\end{aligned}$$

From history. Tailors traditionally ended an apprenticeship by making a “masterpiece,” a complete garment judged by the guild's masters, before they could open their own shops. Your capstone is a masterpiece in that old sense: proof of what you can do.

WORKED EXAMPLES

Example 1. A button-front shirt needs $2\frac{3}{8}$ yd of 45-in cotton at \$9.99, $\frac{1}{2}$ yd interfacing at \$3.49, 9 buttons at \$0.35, and thread at \$3.99. Find the budget.

Show solution

1. Fabric: $2.375 \times 9.99 = 23.73$; interfacing $0.5 \times 3.49 = 1.75$; buttons $9 \times 0.35 = 3.15$; thread 3.99.
2. Total: $23.73 + 1.75 + 3.15 + 3.99 = 32.62$.

Answer: About \$32.62.

Example 2. The actual costs came to \$36.10 because you bought $\frac{1}{4}$ yd more fabric and better buttons. Find the variance as an amount and a percent of the budget.

Show solution

1. Variance: $36.10 - 32.62 = 3.48$.
2. Percent: $\frac{3.48}{32.62} \times 100\% \approx 10.7\%$.

Answer: \$3.48 over budget, about 11%. Record why, so the next estimate is better.

Example 3. Plan the time. Steps and estimates: muslin 4 h, fitting and pattern changes 2 h, cutting and marking 2 h, construction 12 h, finishing (buttonholes, hems, pressing) 4 h. At 6 hours a week, how many weeks to finish?

Show solution

1. Total: $4 + 2 + 2 + 12 + 4 = 24$ h.
2. Weeks: $24 \div 6 = 4$ weeks.

Answer: About 4 weeks; add a week of margin for unpicking and refitting.

PRACTICE

1. **Easy** Name four parts of a design brief.

Show answer

Who it is for, purpose, requirements (fit, modesty, care, budget), success criteria.

2. **Easy** What is a construction log?

Show answer

A dated record of every step, decision, problem and fix.

3. **Easy** Why make a muslin before cutting capstone fabric?

Show answer

To test and correct fit before cutting good fabric.

4. **Medium** Budget \$45, actual \$41.40. Find the variance and percent.

Show answer

-\$3.60, about 8% under budget.

5. **Medium** A garment costs \$48 and is expected to be worn 120 times. Projected cost per wear?

Show answer

\$0.40.

6. **Medium** Choose a fiber and weave for a hard-wearing vest for outdoor chores, and explain.

Show answer

For example, a cotton or wool twill (dense, durable, hides soil), with a smooth cotton or polyester lining.

7. **Medium** Why is preshrinking essential for a capstone?

Show answer

So the garment keeps its fitted size after washing and seams do not pucker.

8. **Hard** Construction estimate 20 h, actual 27 h. By what percent did you underestimate, and how would you adjust future estimates?

Show answer

$7/20 = 35\%$ $7/20 = 35\%$; add about a third to future estimates, or log step times to estimate better.

9. **Hard** List the critical path for a lined vest from design to finish.

Show answer

Brief, pattern, muslin and fitting, pattern changes, cut and interface, darts and shoulder seams, bag lining, turn and press, side seams, buttonholes and buttons, final press.

10. **Hard** A skirt needs $1\frac{7}{8}$ yd of 60-in wool at \$18.99 and 1 yd of lining at \$6.49, a zipper \$2.50, interfacing \$1.25, thread \$3.99. Total?

Show answer

$35.61 + 6.49 + 2.50 + 1.25 + 3.99 = \$49.84$ $35.61 + 6.49 + 2.50 + 1.25 + 3.99 = \$49.84$

11. **Challenge** Write three success criteria for your own capstone that are measurable, and explain how you will check each.

Show answer

For example: fits with 3–5 in of chest ease (measure); all seams finished and pressed with no visible puckers (inspect inside and out); finished within 10% of budget (cost sheet). Credit for measurable, checkable criteria.

COMMON MISTAKES

- Choosing a garment far beyond your skills. Stretch one step; finish well.
- Skipping the muslin to save time. It saves fabric, time and disappointment.
- Rushing the finish. Pressing, threads and hems decide how the garment looks.

Make it a game · Capstone Countdown. Write every capstone step on a card. Each week, the family draws the next card, and the student explains the step and the plan for it in one minute. Finish a step on time and keep the card; at the end, the cards become the timeline in the portfolio.

UNIT 10 TEST

Calculators are allowed. Show your work for every calculation: write the formula, substitute with units, and give the answer with its unit. Answer concept questions in complete sentences. The test is worth 100 points.

1. (7 pts)
Describe how canvas and pad stitching give structure to a tailored coat.
2. (7 pts)
A strip overhangs 6.4 cm at 41.5° ; the fabric weighs 250 g/m². Find c and G.
3. (7 pts)
If bending length increases by 50%, by what factor does G increase (same weight)?
4. (7 pts)
Compare fusible and sew-in interfacing.
5. (7 pts)
Shorten jeans 2½ in by the original-hem method and take 3 in out of a shirt at two side seams. Give the tuck depth and per-edge amount.
6. (7 pts)
List the worth-it test questions for an alteration.
7. (7 pts)
Who was Dorcas, and how did her work continue in church history?
8. (7 pts)
Damage 3 × 2 in, margin 1 in, turn-under ¼ in. Patch size? Why cut it on the garment's grain and preshrink it?
9. (6 pts)
A darn 2 in wide at 14 threads per inch: how many warp passes?
10. (7 pts)
Coat A \$150, 6 years × 50 wears, \$30 care; coat B \$50, 2 years × 50 wears, \$5 care. Compare cost per wear.
11. (6 pts)
Materials \$28, 6 h of work. Find the make cost at \$0/h and at \$10/h.
12. (6 pts)
Give four fiber-based care rules for a wardrobe.
13. (6 pts)
A capstone was budgeted at \$52 and cost \$57.20. Find the variance and percent.
14. (6 pts)
Name the main stages of a capstone project in order.
15. (7 pts)
Short essay (5–7 sentences): Using this unit's stories (Moroni's tailor, Make Do and Mend, Dorcas, Proverbs 31) and your own work, explain how tailoring, alteration and mending are forms of stewardship and service.

UNIT PROJECT: THE CAPSTONE GARMENT AND PORTFOLIO

Design, fit, construct and finish a modest, useful capstone garment for yourself or someone else, meeting a written design brief with measurable success criteria.

Present a complete portfolio: brief, sketches, fabric choice with fiber and weave reasoning, pattern and muslin fitting notes, dated construction log, cost sheet with budget variance and projected cost per wear, photographs of the garment worn or given, and an honest evaluation. Include your Lesson 10.2 alterations and Lesson 10.3 mends as evidence of the year's practical skills.

LOOK FOR	WHAT IT MEANS
Design and pattern	The brief is clear and measurable; the design, fabric and pattern suit the person and purpose, modestly and practically.
Fit	The muslin was fitted and changes transferred; the finished garment fits as the brief requires.
Workmanship	Seams, finishes, closures, hems and pressing meet the standards of Units 7–9.
Construction log	The log is dated and complete, with steps, times, problems and fixes.
Cost analysis and evaluation	Costs, variance and cost per wear are correct, and the evaluation honestly checks every success criterion.

ANSWER KEY

1. Springy canvas sewn behind the front and lapels adds stiffness and resilience; small pad stitches join it to the cloth while both are rolled over the hand, building a permanent curve set further by steam pressing.
2. $c = 3.2 \text{ cm} = 3.2 \text{ cm}$; $G = 0.025 \times 32.77 \approx 0.82 \text{ g} \cdot \text{cm}$; $G = 0.025 \times 32.77 \approx 0.82 \text{ g} \cdot \text{cm}$.
3. $1.5^3 \approx 3.41.53 \approx 3.4$
4. Fusible: fast, firm, can bubble and stiffen the hand. Sew-in: keeps drape, can be shaped and pad stitched, takes longer.
5. Tuck $1\frac{1}{4}$ in; $\frac{3}{4}$ in per edge.
6. Is the fabric good and garment sound? Will the alteration make it truly wearable? Will it be worn often? Do time and cost compare well with replacing it?
7. A disciple of Joppa (Acts 9) full of good works who made coats and garments for widows; God raised her through Peter. Dorcas societies in churches later met to sew and mend for the poor.
8. $5\frac{1}{2} \times 4\frac{1}{2}$ in. Same grain so it stretches and hangs like the garment; preshrink so it does not shrink and tear the garment (Mark 2:21).
9. 28.
10. A: $180/300 = \$0.60$; B: $55/100 = \$0.55$. B is slightly cheaper per wear, but A lasts longer and may fit and wear better; a fair judgment weighs both.
11. \$28 and \$88.
12. Wool cool and gentle; no chlorine on wool, silk or spandex; dry cotton and linen fully to prevent mildew; store protein fibers clean (moths); air synthetics for odors; fold heavy knits (any four).
13. \$5.20 over, 10%.
14. Brief, design and fabric choice, budget and schedule, pattern and muslin fitting, cutting and construction, fitting and finishing, evaluation and presentation.
15. A strong essay connects skilled work honored by Scripture and art, thrift and care for what we own, mending and giving to others like Dorcas, and wise valuation like the Proverbs 31 woman, illustrated with the student's own alterations, mends and capstone.

MIDTERM EXAM

Covers Units 1–5. Time: 100 minutes.

You have 100 minutes. A calculator is allowed; no notes. Use $1 \text{ oz/yd}^2 \approx 33.9 \text{ g/m}^2$, $\text{tex} = \text{grams per } 1,000 \text{ m}$, $\text{denier} = \text{grams per } 9,000 \text{ m}$, $\text{Ne} = 590.5 \div \text{tex}$, $1 \text{ lb} = 453.6 \text{ g}$ and $1 \text{ in} = 25.4 \text{ mm}$. For every calculation write the formula, substitute with units and give the answer with its unit; correct work earns partial credit. Answer concept questions in complete sentences. The exam has 26 problems worth a total of 100 points.

1. **3 pts** Lesson 1.1
A gin turns 2,500 lb of seed cotton into 900 lb of lint. Find the lint turnout and the number of 480-lb bales.
2. **3 pts** Lesson 1.1
In two or three sentences, tell honestly how Whitney's gin changed the South.
3. **4 pts** Lesson 1.2
Explain why cotton absorbs water and wrinkles, using cellulose's structure.
4. **4 pts** Lesson 1.2
A swatch weighs 30.0 g dry and 32.6 g conditioned. Find regain and moisture content.
5. **4 pts** Lesson 1.3
What did Mercer discover in 1844, and what three properties does mercerization improve?
6. **4 pts** Lesson 1.4
List the steps from flax to linen yarn, and explain why linen wrinkles.
7. **4 pts** Lesson 1.5
Describe the burn behavior of cellulose, protein and synthetic fibers.
8. **3 pts** Lesson 1.5
A 500 g tablecloth is 55% linen, 45% cotton. Find each fiber's mass.
9. **4 pts** Lesson 2.1
Name the parts of a wool fiber and explain wool's resilience.
10. **4 pts** Lesson 2.2
A greasy fleece of 5.0 kg yields 2.9 kg clean. Find the yield and the clean price if greasy wool sells for \$4.64 per kg.
11. **4 pts** Lesson 2.3
List the four conditions for felting, and find the area shrinkage of a $10 \times 10 \text{ cm}$ square that felts to $8 \times 7.5 \text{ cm}$.
12. **3 pts** Lesson 2.3
Explain Mark 2:21 using shrinkage.
13. **4 pts** Lesson 2.4
Give one distinctive property and its cause for mohair, cashmere and alpaca.
14. **4 pts** Lesson 2.5
Raw silk of 72 g degums to 55 g. Find the loss and name the protein removed. Who brought silkworm eggs to Justinian, and about when?
15. **4 pts** Lesson 3.1
Why is rayon weaker wet while cotton is stronger wet, though both are cellulose?

16. **4 pts** Lesson 3.2
Tell the discovery of nylon 6,6 in two sentences, including cold drawing.
17. **4 pts** Lesson 3.3
Name the three spinning methods and one fiber made by each, and explain why polyester dries fast.
18. **4 pts** Lesson 3.4
A knit's 10.0 cm mark stretches to 13.8 cm and recovers to 10.4 cm. Find elongation, recovery and growth.
19. **4 pts** Lesson 3.5
A 150-denier yarn has 300 filaments. Find the dpf. Is it a microfiber? Write a fair one-sentence verdict on polyester.
20. **4 pts** Lesson 4.1–4.2
Explain why a staple yarn's strength rises with twist and then falls.
21. **4 pts** Lesson 4.2–4.3
Match: Hargreaves, Arkwright, Crompton, Slater, Lowell to their contributions and dates.
22. **4 pts** Lesson 4.4
25.0 m of yarn weighs 4.0 g. Find its tex, denier and cotton count.
23. **4 pts** Lesson 4.5
A 27-tex thread breaks at 1,458 g. Find its tenacity in g/den. Why are singles plied in the opposite direction?
24. **4 pts** Lesson 5.1–5.2
A 10×10 cm square weighs 3.20 g. Find GSM and oz/yd². Name the weave of denim and why its back is lighter.
25. **4 pts** Lesson 5.3
A sheet shows 50 ends and 45 picks per $\frac{1}{2}$ in of 2-ply yarns and is labeled 380. Find the true count and explain the label. How did a Jacquard card control the loom?
26. **4 pts** Lesson 5.4–5.5
Distinguish weft and warp knits, and give the two moves of bobbin lace.

ANSWER KEY

1. $900/2,500 = 36\%$; $900/2,500 = 36\%$; $900/480 = 1.875$; $900/480 = 1.875$ bales.
2. It made short-staple cotton cheap to clean, so cotton spread across the Deep South; since planting and picking were still hand work, slavery grew greatly, from about 700,000 enslaved people in 1790 to nearly 4 million by 1860.
3. Cellulose's many -OH groups attract water into amorphous regions; bent wet, hydrogen bonds break and re-form with chains in new positions, holding wrinkles.
4. Regain $2.6/30.0 = 8.7\%$; $2.6/30.0 = 8.7\%$; content $2.6/32.6 = 8.0\%$; $2.6/32.6 = 8.0\%$.
5. Strong caustic soda swells cotton, making it stronger and more dye-receptive (and shrinking it); improvements: luster, strength, dye uptake.
6. Pulling, retting, breaking, scutching, hackling, spinning. Linen's highly crystalline, parallel cellulose stretches only 2–3%, so creases bend it past recovery.
7. Cellulose: quick ignition, paper smell, afterglow, soft gray ash. Protein: sputters, burning-hair smell, self-extinguishes, crushable black bead. Synthetics: shrink and melt, drip, chemical smell, hard bead.
8. 275 g linen, 225 g cotton.
9. Cuticle, cortex (and medulla). Coiled keratin chains tied by disulfide and other cross-links stretch and spring back.
10. 58% ; $4.64/0.58 = \$8.00$; $4.64/0.58 = \$8.00$ per clean kg.
11. Moisture, heat, soap or alkali, agitation; $(1 - 60/100) = 40\%$; $(1 - 60/100) = 40\%$.
12. Unshrunk new cloth shrinks when washed; sewn onto an old shrunk garment, it pulls and makes the tear worse.
13. Mohair: luster (flat scales). Cashmere: softness (fine, $\leq 19 \mu\text{m}$). Alpaca: light warmth (partly hollow fibers, little grease).
14. $17/72 \approx 23.6\%$; $17/72 \approx 23.6\%$; sericin. Monks, around AD 552.
15. Rayon's short chains and low crystallinity let water push chains apart so they slide; cotton's long, ordered chains hold, and swelling evens stress.
16. In Carothers's DuPont group, Julian Hill found in 1930 that stretching a cooled polymer thread made it much stronger (cold drawing). On February 28, 1935, Gerard Berchet made nylon 6,6, sold as toothbrush bristles (1938) and stockings (1940).
17. Wet (rayon), dry (spandex, acetate), melt (polyester, nylon). Polyester's chains have almost no water-loving groups; regain about 0.4%, so it holds little water.
18. 38% ; $3.4/3.8 \approx 89\%$; $3.4/3.8 \approx 89\%$; 4%.
19. 0.5 dpf, a microfiber. Polyester is strong, quick-drying, wrinkle-resistant and inexpensive but absorbs little, holds oily odors and melts under high heat.
20. Twist squeezes fibers so friction holds them; past the optimum, fibers tilt too far from the axis, so less of their strength acts along the yarn.
21. Hargreaves: spinning jenny, c. 1764. Arkwright: water frame, 1769 (Cromford mill 1771). Crompton: mule, 1779. Slater: water-powered spinning at Pawtucket, 1790. Lowell: integrated mill at Waltham, 1814 (Lowell mills 1820s).
22. 160 tex; 1,440 denier; $590.5/160 \approx 3.7$; $590.5/160 \approx 3.7$ Ne.
23. $1,458/243 = 6.0 \text{ g/den}$; $1,458/243 = 6.0 \text{ g/den}$. Opposite ply twist balances the singles' twist so the yarn is stable and does not kink.
24. 320 g/m^2 , 9.4 oz/yd^2 . A warp-faced (3/1) twill: indigo warp floats on the face, undyed weft shows on the back.
25. 190 true count; plies counted twice. A hole let a needle through so its hook lifted one warp end; one card per pick.
26. Weft knit: one yarn forms courses across (T-shirts, hand knits); warp knit: many lengthwise yarns loop into neighbors and resist runs. Bobbin lace: cross and twist.

FINAL EXAM

Covers Units 1–10. Time: 120 minutes.

You have 120 minutes. A calculator is allowed; no notes. Use $1 \text{ oz/yd}^2 \approx 33.9 \text{ g/m}^2$, tex = grams per 1,000 m, denier = grams per 9,000 m, $\text{SPI} = 25.4 \div \text{stitch length in mm}$, $^{\circ}\text{C} = 5/9(^{\circ}\text{F} - 32)$ and $1 \text{ in} = 25.4 \text{ mm}$. Show the formula, substitution with units and the answer with its unit for every calculation. Answer concept questions in complete sentences. The exam has 30 problems worth a total of 100 points.

1. **3 pts** Lesson 1.1
At 35% turnout, how much seed cotton makes one 480-lb bale?
2. **3 pts** Lesson 1.2
Explain why cotton is stronger wet.
3. **3 pts** Lesson 1.4–1.5
How do you tell linen from cotton when both burn the same way?
4. **4 pts** Lesson 2.1–2.3
Explain why wool keeps you warm when damp and why it felts.
5. **3 pts** Lesson 2.5
Why must chlorine bleach never be used on silk or wool?
6. **4 pts** Lesson 3.1–3.3
Contrast regenerated and synthetic fibers with two examples each, and describe melt spinning.
7. **3 pts** Lesson 3.4
How do soft and hard segments give spandex stretch and recovery?
8. **3 pts** Lesson 4.4
Convert 40 tex to denier and to Ne.
9. **3 pts** Lesson 4.3
What did Lewis Hine's photographs help accomplish?
10. **4 pts** Lesson 5.1–5.2
A runner 15 in wide by 50 in finished, at 12 EPI, 10% take-up and 24 in loom waste: find ends and warp yardage.
11. **3 pts** Lesson 5.3
What does thread count tell you, and what does it not?
12. **3 pts** Lesson 6.1
How much alum (15% WOF) and water (30:1) for 160 g of wool?
13. **4 pts** Lesson 6.2
Tell Perkin's discovery in two sentences and match acid, reactive and disperse dyes to fibers.
14. **3 pts** Lesson 6.3
How many 3-in repeats fit across 44 in with $\frac{1}{2}$ in unprinted at each edge, and what is the half-drop offset for a 4-in vertical repeat?
15. **4 pts** Lesson 6.4
Explain Sanforizing and durable press, and give the Triangle Shirtwaist fire's main safety lessons.

16. (3 pts) Lesson 6.5
What do the TFPIA (1958) and the Care Labeling Rule (1971) require?
17. (3 pts) Lesson 6.5
Why rinse blood in cold water and treat it with an enzyme detergent?
18. (4 pts) Lesson 7.1–7.2
Describe how a lockstitch forms and diagnose loops of top thread showing underneath.
19. (3 pts) Lesson 7.1
Convert 2.5 mm and 3.5 mm stitch lengths to SPI.
20. (3 pts) Lesson 7.3
Fabric breaks at 15.0 kg and a flat-felled seam at 13.8 kg. Find the seam efficiency.
21. (3 pts) Lesson 7.4–7.5
Give two serger safety rules and convert 300 °F to °C.
22. (4 pts) Lesson 8.1–8.2
Who began graded patterns, and when? A garment laid flat measures 22 in at the hip; the body hip is 39 in. Find the ease.
23. (3 pts) Lesson 8.2
State the course's rules for taking body measurements.
24. (3 pts) Lesson 8.3–8.4
Add 2 in of hip room at four side-seam edges. How much per edge? Why must the grainline be measured at both ends?
25. (3 pts) Lesson 8.5
Grade a pattern two sizes up at 1½ in of hip per size over four edges. How far does each side seam move?
26. (4 pts) Lesson 9.1–9.2
A waist edge of 16 in must finish at 13½ in with two darts. Find each intake. Waist 32 in: elastic cut 3 in shorter plus 1 in overlap?
27. (3 pts) Lesson 9.3
Who designed the modern zipper and when, and why leave a pouch's zipper half open before the final seams?
28. (4 pts) Lesson 9.4–9.5
When do you clip and when notch a curve? Space 6 buttons over 22½ in, and size a buttonhole for a ¾-in button ⅛ in thick.
29. (3 pts) Lesson 10.1–10.4
A \$60 jacket worn 200 times with \$20 of care: cost per wear? A strip with $c = 3.0$ cm and $W = 0.030$ g/cm²: find G .
30. (4 pts) Lesson Synthesis
Short essay (6–8 sentences): Choose fabric and construction for a durable, modest work shirt for a family member. Justify fiber, yarn, weave, weight, finishes, seams and care, using at least five ideas from different units, and explain how making it is an act of stewardship and service.

ANSWER KEY

1. $480/0.35 \approx 1,371$ lb $480/0.35 \approx 1,371$ lb
2. Water swells the fiber, relieving stress at weak points so the long, ordered cellulose fibrils share load more evenly.
3. Under magnification linen shows straight fiber bundles with nodes and slubby yarn; cotton is a twisted ribbon; linen feels cool and stiff; a damp flax fiber twists clockwise as it dries.
4. Wool absorbs much water vapor inside the fiber (with heat of sorption) while its crimp traps still air; felting comes from directional scales ratcheting fibers together under heat, moisture, soap and agitation.
5. It attacks and dissolves protein fibers.
6. Regenerated: natural polymer re-formed (rayon, lyocell); synthetic: built from small molecules (nylon, polyester). Melt spinning: melt chips, pump through a spinneret, cool in air, draw to align chains.
7. Soft segments uncoil under load; hard segments cluster into hydrogen-bonded tie points that pull the chains back.
8. 360 denier; Ne ≈ 14.8 .
9. They exposed child labor in mills and helped win state laws and the 1938 Fair Labor Standards Act's limits on child labor.
10. 180 ends; $50 \times 1.1 + 24 = 79$ in $50 \times 1.1 + 24 = 79$ in; $180 \times 79 = 14,220$ in ≈ 395 yd $180 \times 79 = 14,220$ in ≈ 395 yd.
11. It counts yarns per square inch (density); it does not tell fiber quality, yarn fineness, weave or finish, and ply-counting can inflate it.
12. 24 g alum; 4.8 L water.
13. In 1856 eighteen-year-old William Perkin, trying to make quinine from coal-tar aniline, obtained a purple that dyed silk fast; he founded the synthetic dye industry. Acid: wool, silk, nylon; reactive: cotton, linen, rayon; disperse: polyester.
14. 14 repeats; 2 in.
15. Sanforizing compresses cloth lengthwise to remove future shrinkage; durable press cross-links cellulose so cotton resists wrinkles. The 1911 fire (146 dead) led to fire drills, sprinklers, unlocked and marked exits and stronger factory laws.
16. Generic fiber names and percentages, maker or seller, and country of origin; and a permanent label with at least one safe care method.
17. Heat cooks protein onto the fiber; protease enzymes digest the protein stain.
18. Needle carries top thread down; a loop forms as it rises; the hook carries the loop around the bobbin; the take-up lever tightens; feed dogs advance. Loops underneath mean top tension is too loose (often threaded with the presser foot down).
19. 10.2 and 7.3 SPI.
20. 92%.
21. Unplug before threading or opening covers; never serge over pins (keep fingers from the knife). 149 °C.
22. Ebenezer and Ellen Butterick, 1863. Ease $44 - 39 = 5$ in $44 - 39 = 5$ in.
23. Over light clothing, by a parent (father for son, mother for daughter for older students), recorded privately for fit only, never judged or compared.
24. $\frac{1}{2}$ in per edge. So the arrow is truly parallel to the selvage; otherwise the piece is off-grain and will twist.
25. $\frac{3}{4} = 0.75$ in $\frac{3}{4} = 0.75$ in outward.
26. $1\frac{1}{4}$ in each; 30 in.
27. Gideon Sundback, 1913 (patented 1917). So the pouch can be turned right side out through the opening.
28. Clip concave curves, notch convex. Spacing $4\frac{1}{2}$ in. Buttonhole $\frac{7}{8}$ in.
29. \$0.40 per wear; $G = 0.030 \times 27 = 0.81$ g · cm $G = 0.030 \times 27 = 0.81$ g · cm.
30. A strong essay reasons from data and chemistry (e.g., cotton or cotton/polyester twill or oxford, about 150–200 g/m², preshrunk, perhaps durable-press, flat-felled seams, polyester or core-spun thread, interfaced collar and cuffs, correct care label), fits the wearer from a muslin, and connects the work to stewardship and service (Dorcas, Hannah, Proverbs 31).