Design a Textile Mill

You have been transported back to the 1840s. The wealthy capitalist investor, Mr. Buggé has just purchased the land along the Millstone River and is looking to build a textile mill to replicate the success of the factories in Lowell, Massachusetts. Your company has been offered the opportunity to submit a proposal that would essentially build and operate the mill in a manner that everyone makes money and Mr. Buggé receives a handsome profit. The proposal is due on February 20th when your team will present your idea to Mr. Buggé.

This assignment makes use of all the 21st Century competencies. There are multiple problems to be solved, crossover knowledge of science, math and business as well as historical understanding of the textile business at the time. You must be collaborative team members, information literate researches, creative and practical problem solvers, globally aware, effective communicators, and self-directed learners.

This project is open-ended in the design. That means you as an individual, and part of the team must think about this project. What should be in the written portion? How much will be orally presented? Will you draw your design? Will you create a 3d model of your design? What will your final piece be? What will you call my company? How will I know what it will look like? These are just some of the problems your team must solve. You will need to research the mill system beyond what we discussed in class in order to fully understand the needs of building a successful industrial textile mill.

At the end of the project you will be tasked with assessing yourselves, your teammates, and the group’s overall performance. In other words I want to know what you think you, your teammates and group deserve.

Be creative! Think outside the box! Have fun!

Mr. Buggé

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<tr>
<th>Team A</th>
<th>Team B</th>
<th>Team C</th>
<th>Team D</th>
<th>Team E</th>
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<td>Ralles</td>
<td>Olu</td>
<td>Sam W</td>
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<td>Ally</td>
<td>Greg</td>
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<td>Varshini</td>
<td>Phuong Anh</td>
<td>Maya</td>
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Deliverables on Wednesday February 20th are: Your mill design complete with information in the packet on how it will work, costs, projected productivity, etc. Additionally you will need to turn in an annotated bibliography of your research separated by primary and secondary sources. Finally you will be reflecting back on the assignment, your own participation and group involvement as well as the working interactions of your teammates.
Introduction

A textile factory is a system of machines, workers, managers, power, and materials, all brought together to produce cloth and make money. The textile mills at Waltham, MA (1813) and then the mills at Lowell, MA (1824) were the first textile mills in the world that took in raw cotton, performed all of the manufacturing processes under one roof, and turned out finished cloth. You and your fellow capitalists believe you have the strength to start your own business in a new town founded by that well know financial wizard Mr. Buggé. You just purchased land along the Millstone River in Buggé, New Jersey and believe it can be the next Lowell.

The goal of this activity is for you to understand:
- the scale of production and systems of manufacturing
- how to staff and manage a mill
- to solve complex relationships between people, power and machines
- the process of producing textiles during the nineteenth century

Materials:
- You are being supplied
  - The architectural diagram of a factory floor
  - A table of approximate wages paid at the time

The assignment
Textile mills, like other factories, are complicated systems. One of the key jobs of a factory owner or manager is to set up the machinery in the factory so that one machine produces just enough to supply the next process. It's not easy to balance the various machines so that the output of each stage would not produce too much or too little for the next stage.

Your job is to use the drawings and any other information supplied or researched on your own, then build and staff a factory. You need to answer the basic questions… How many machines, how many people, and how much money was needed to run a factory? While the numbers you are given will not be exact, they will closely represent the circumstances
of an early 19th-century factory.

Setting up the factory—calculating the number of each type of machine—is only your first step. The factory manager (you) also have to fit the machines into the mill, consider how much money the machines would cost, and worry about finding the right workers to operate the machines. In addition, the manager had to run the mill to make money—paying for the machines, the workers, the power, and the raw materials.

These exercises show some of the mathematics that the mill manager had to do. It's mostly simple math—multiplication, division, and proportions. But for the mill manager, the math was the easy part of the problem; the hard part was estimating the right relationships between the machines, knowing how fast machines ran, how much power they used, and how many people were needed to keep them running. Mistakes, for example buying the wrong machines, or hiring the wrong people, were expensive. You will need to become familiar with the terms used for the different machines and processes in the textile mill.

Finally you will be delivering, at minimum, a poster board sized schematic type drawing and explanation of how your factory is built and staffed.

**EXERCISE 1: HOW MANY MACHINES?**

Decide how many machines of each kind to buy for your factory. To do this, follow these rules that compare the input and output of each type of machine. Step 1 is to determine the ratios of the machines to one another, that is, how many of each of the other machines are there for each picking machine. Then you should move on to decide how many, and what kind of machines, you need in total.

**Machines used in producing cotton cloth:**

- **Carding machine.** Straightens the fibers of raw cotton. A single picker can supply cotton for eight breaker carding machines, the first step. The output of these machines then goes to the finishing breakers; for every breaker card there's one finishing card. The carding machine produces "slivers," long loosely twisted pieces of cotton fibers which then go to the drawing frame, which draws and twists it. There are three kinds of drawing frames. You need one of each kind of drawing frame for every four finishing cards.

- The **drawing frame** is the last of the preparatory processes. Next comes spinning. The first step is to turn
the sliver into roving, which is done on a "speeder." The Lowell factories had two speeders for every three drawing frames.

The next step in spinning is to make the yarn. The Lowell mills used throstle spinners. Each speeder made enough roving to supply three throstle spinners. There were two kinds of throstle spinners, one kind for the warp yarn and one kind for the filling yarn. There were twice as many warp throstles as filling throstles.

Next comes weaving, turning the yarn into finished cloth. First, the yarn must be "dressed," coated with a starch solution to make it easier to work. You need one dressing frame for every 16 looms.

Before the looms can be set up, you have to wind the warp, putting it on the warp beam. One warper will provide enough warp beams for 20 looms.

There are almost as many looms as all the other machines put together, 10 looms for every filling throstle.

**EXERCISE 2: HOW MUCH POWER?**

Now figure out how many machines the waterpower on the site can drive. At the Waltham mills, the limiting factor was power. A "millpower" provided about 85 horsepower, of which more than a third was lost to inefficiencies--so there was about 60
horsepower available to drive the machines. Each machine took about (on average) .186 h.p. How many total machines were there, and how many of each machine?

EXERCISE 3: HOW MANY WORKERS DO YOU NEED?

Here's how many of each machine a worker could operate:

Women's jobs:
One weaver could tend two looms.
A spinner could tend one filling throstle or two warp throstles.
One woman tended each drawing frame.
A woman could handle two speeders.
Each dressing frame required one woman; in addition, there was one woman for every two dressing frames who did "drawing in," drawing each thread through the harness and reed of the loom. "Spare hands" were trainees who were learning to work the machines. There was, on average, one spare hand for every four experienced women workers.

Men's jobs:
Men tended the pickers and carders; one man per picker and one man per ten carders,
Overseers and assistant overseers were men: there was, on average, one of these managers for every thirty female employees.
Machinists kept the machines operating. There was one machinist for every 50 or so machines.

EXERCISE 4: PAY DAY
Each worker is paid a different amount. The wages were determined by a number of factors:
- More skilled workers tended to get paid more than those less skilled.
- Young workers tended to get paid less than older workers.
- Women got paid less than men.
- Workers with needed skills received more than those with common skills.

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<tr>
<th>Job Category</th>
<th>Wages Per Day</th>
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<tr>
<td>Weaver</td>
<td>.66</td>
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</table>
Spinner .58
Drawer .52
Speeder .66
Dresser .78
Drawing in .66
Spare hands .44
Pickers .85
Carders .85
Overseers 1.75
Machinist 1.27

What is the weekly payroll of your mill?

EXERCISE 5: FLOOR DESIGN

Examine the attached floor plans for each floor of the mill. The keys provide information about the floor plans. Using the information in Exercise 1, trace the flow of the material through the mill. (The first step, picking, is not shown; picking machines were kept in a separate building because they occasionally caught fire.) Why do you think that the machines are set up the way they are? How would you change the setup to make it more efficient.

The architectural drawings below are supplied by Patrick Malone, Brown University, Providence, RI. Used by Permission.
Key to machines

Schematics of the various machines
Yarn Spinning

SPINNING A YARN

"IS THAT A RALE SWINGING FROM YOUR SHOULDER?"

Yarn may be produced on a machine that is called a spinning wheel. It consists of inner spindles arranged in a long row all spinning together. The machine operator places yarn on the spindles and sets it in motion using long yarns by dragging a lightweight ball of yarns over a long strip. By moving the Camel's back, which the raw yarns are then wound onto the final bobbins. This winding bobbins are what allow the easy storage, transportation, and use of the mass produced yarn.

Automatic Loom

SHUTTLE

HEDDLE "A" UP

Side View of Weaving Process

Drawing Out and Adding Twist to Yarn

Drawing Out and Twisting

Winding Yarn on Bobbin and Returning for next Drawing Out

Twisting and Winding
"Why A Factory?"

Factories are places that rely on the division of labor to mass-produce items for a profit. They often rely on machines (as well as people) to produce items more cheaply than would be possible if a craftsman produced the goods. Factories didn't come into existence automatically, as if there were no other possible ways to organize production, and that is particularly true for cloth making. In England, for example, cloth merchants often "put out" raw materials to artisans who worked at home or in shops where several people would labor together. Some things--straw hats and shoes, for instance--were made that way in America, too. But most early textile factories in this country tended to emerge from two lines of development. In one case, they grew out of existing water-powered milling operations. So, for instance, a miller added a carding machine to the equipment of a gristmill or sawmill, drawing upon the waterpower already in use at the site. That experiment then often led an owner to introduce some of the new spinning machines and power looms, in many cases taking out the older grist or saw mill machinery, and by such a process a textile mill was created. These kinds of factories were often small and oriented to local markets. By 1815 there were lots of them, especially in southern New England.
In the second case, textile factories were established as complete enterprises from the beginning, depending on the development of new power sources and the identification of new populations of labor. This is what happened at Waltham, MA in 1813, at Lowell, MA in 1822, and then later at Manchester, NH, and other places in northern New England. The men who established these factories were originally looking for new kinds of investments because the shipping they were engaged in had become too risky during the early 19th century as a result of the international hostilities, which led up to and continued during the War of 1812. These merchants were able to combine large amounts of capital (which were unavailable to almost everyone else in the United States) with powerful water sources to create large factories oriented towards national markets.

From an investor's or a manager's point of view, the advantages of combining raw materials, workers, machines, and power—all under one roof—were obvious. One of the first benefits was better supervision of workers and work processes. Someone working at home without the pressure of immediate supervision might not work as hard or as regularly. Working and drinking (not an uncommon practice in some early industries) could also result in less than perfect yarn or cloth. With workers in a single place for 11-to-13 hours a day, almost all these problems could be minimized, giving managers a more predictable output-per-week at a lower cost-per-yard.

Employing the new textile machinery in a water-powered factory setting provided huge gains in productivity and that was another important benefit for mill owners. Single spinning machines and power looms spun and wove much faster than individuals could; assembling a great many of these machines, with each worker tending several at once, multiplied the possibilities for profits. Here is an important difference from plantations, where gains in productivity came only by adding more workers.

But like plantation owners, factory managers also had to be concerned with discipline, to insure control over production. Small factories employed families, relying primarily on the labor of children (usually between the ages of 10 and 20) to produce cloth. The large factories of places like Lowell employed young women (usually between the ages of 13 and 25) to produce their cloth. In both cases, factory managers argued that these groups of people needed close supervision because they could not be trusted to take care of themselves. Some owners argued that poor families who did not work in factories would only become idle, immoral, and even criminal. Those who employed young women in places such as Lowell did not feel that these young women were likely to become immoral, but they did feel that the women needed to live in boarding houses with strict rules of behavior, and they certainly never expected these young women to move up the factory ladder to become overseers, much less owners. Although factory workers were given more independence than slaves, factory owners still looked down upon them.

However, in the North, factory owners paid wages to their workers (or the parents of their workers where family labor was used). They expected their workers to provide their own
food and clothing and they expected their workers to depend on family members for support in a time of crisis. In this way, northern workers were treated differently from slaves. Factory owners only claimed to own the labor of their employees, not their whole person.

Cotton production resulted in the spread of slavery; textile production resulted in the beginnings of a class of factory workers who had limited prospects in the industrial world. In the South, slave owners looked down on slaves because of their race; in the North, factory owners looked down on operatives because of their economic background (class) and because they were female.

Many northern factory workers were no more enamored of their jobs than slaves were of theirs. Indeed, they sometimes called themselves wage slaves. Factory workers organized collectively to resist unfair labor conditions more regularly than slaves did, no doubt because the consequences for such behavior were less severe than on southern plantations. But factory workers also engaged in day-to-day resistance by quitting their jobs and by working more slowly than their overseers demanded.

Thus factories, like plantations, were set up to increase profits for their owners. However, factories increased profits not only through the organization of labor, but through the development and spread of technology.

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Water Power

Three WaterWheels.
Courtesy of Slater Mill Historic Site, Pawtucket, RI.
Water power was the prime mover of the Industrial Revolution. Waterwheels used the power of water running downstream in a river to turn machinery. However, water power was nothing new. Water-powered devices had been used, even in some textile processes, for nearly two thousand years. Mills mechanized a number of very tedious tasks. Waterwheels powered grist mills for grinding grain into flour, saw mills for carving lumber out of logs, fulling mills for finishing cloth, and twisting mills for winding silk thread. Neither animals nor people could match the economy and tireless power of water.

The reliance upon water power to run the machinery of the new factories meant that factories had to be built upon a river. Yet not every place upon the river made a good factory site. The best location was where the level of the river dropped to provide more power. Because there are a limited number of good mill sites on each river, a potential mill site was valuable and costly.

![Typical Mill Site](https://example.com/typical_mill_site.png)


*Courtesy of the Hagley Museum, Wilmington, DE.*

To develop waterpower on a site, the millwright commonly built a dam to store water at the highest point above the mill and a channel, called a millrace, to direct the water to the waterwheel and to carry it back to the river. Damming the river to collect water in the millpond often interfered with fishing, farming, and boat travel. So the new water-powered factories often came at the expense of other members of the community who had previously relied upon the river for their own livelihood and convenience.

The use of waterpower also had consequences for the organization of the factory. Because it was difficult to transmit the mechanical energy of the waterwheel over long distances, the factory was located by the riverside. To keep the manufacturing close to the power, mill owners often built two- and three-story factories and transmitted the power by gearing to the upper floors. A central power source like the waterwheel encouraged entrepreneurs to bring the new machinery, raw materials, and workers to one location, an
The development of the mechanized factory led to efforts to improve the efficiency of existing waterpower technologies. A British engineer named John Smeaton analyzed the relative efficiency of two forms of waterwheels, the undershot and the overshot. The average overshot wheel was far more efficient than the undershot, about 65% as opposed to 25%. The undershot wheel is an impulse wheel, since the water imparts its energy by pushing. If the hillside is steep, the water moves fast at the bottom and can push impressively against the paddles of an undershot wheel. The overshot wheel is a gravity wheel. It is a series of buckets attached to the outside of a big circle. The water goes into a container at the top and drops all the way down. The ability to capture more power from a descending river allowed mills to proliferate and in turn further encourage the development of water-powered technologies.
The growth of mills was accompanied by the growth in the power of waterwheels. From the first half of the 18th-century to the first half of the 19th-century, the average horsepower increased 300% to 12-18 horsepower. The largest wheels were 60 and 70 feet in diameter and capable of producing upwards of 250 horsepower. Taking advantage of America's abundance of wood, most waterwheels were constructed of wood. Usually, only the bearings and the gear teeth were made of metal. However, wooden wheels needed replacement roughly every ten years. When American mill owners' waterwheels no longer functioned, they could choose to install turbines instead of new waterwheels. This difference may have had a large role in the Americans' far more rapid adoption of the newest form of waterwheel, the turbine, at midcentury.

Water produced the largest part of industrial power until after the Civil War. In 1790 there were some 7,500 small mills in the United States. In 1825 Maine, New Hampshire, Vermont, and New York had about 16,000 mills. By 1850 some 60,000 mills existed, scattered all across the country. Most of these mills were grist and sawmills, operating seasonally as demand and water were available. Others were part of large mill complexes that made textiles and other manufactured goods. Not until the 1870s did most textile
Stream Flow Measurement: An Experiment

"Weir Dam, for Measurement of Water," *The Construction of Mill Dams*
James Leffel & Co., 1874.

**Description**

In this activity, you will read the essay entitled "Water Power," locate a small stream, and measure the water's depth and speed. Following the directions given in a handout, you will then be able to calculate the water flow.

**Gauging the Waters**

When deciding where a mill should be located, a millwright had to know the river's potential power, which meant computing the flow of the river and measuring the available head (vertical drop) at the site. If there is a stream or creek near your school, you can measure the flow in it. To do this, you must measure the speed and cross section of the stream. The problem with measuring the speed is that it varies from the top to the bottom of the stream because the bottom water is dragging over the mud, sand, or rocks. The best way to approximate the average current speed is to take a bottle, fill it most of the way with water so that it floats submerged to the neck, and then time it as it floats down a measured length (say, thirty feet) near the center of the current. If you repeat the measurement about ten times and average the results you will have a reasonable answer for the stream's speed.
Now you need to calculate the cross section. For this you will measure the width of the stream and then measure the depth in about ten places across the river. (If you can walk across the stream, do this with a tape measure. If it's too deep, you can do this from a boat, by dropping a weight on a string and measuring the length of the string.) Calculate the average depth by adding all of the measurements and then dividing by the total number of measurements. You can then multiply by the stream's width to get a cross section in square feet (area = avg. depth x width). The cross section multiplied by the speed of the stream will give you the flow in cubic feet of water per second.

![Students on a boat taking stream depth measurements](image)

If the stream drops an appreciable amount and you measure that, you can calculate the power available by using the formula

\[
\text{POWER} = \frac{Q h}{11.8} \text{ kilowatts}
\]

where \(Q\) is the flow rate in cubic feet per second and \(h\) is the head in feet. The amount of power in a small stream is quite surprising.
Example

Width of stream = 6.5 feet

Depth measurements (in feet) = .67, 1.25, 1.75, 1.75, 2.5, 2.33, 1.5, 1.5, .75

Average depth = 1.55 feet

Time measurements (in seconds per 30 feet, for example) = 6.5, 5.9, 5.9, 5.7, 5.8, 6.2, 6.1, 5.7, 6.1, 6.0

Average time = 6.0 secs/30 ft, or 1 second for 5 feet, which is the same as a speed of 5 ft/sec.

The cross section is 6.5 ft x 1.55 ft = 10.075 10 sq ft.

The flow is 10 sq ft x 5 ft/sec = 50 cu ft/sec.

If this stream drops 2 feet, then:

$$\text{POWER} = \frac{Qh}{11.8} = \frac{(50)(2)}{11.8} = 8.5 \text{ kilowatts}$$

So this stream could light 80 100-watt lightbulbs.

One thing you miss with the above calculation is that the water on the top of the stream moves faster than the water on the bottom. As early as the 19th century, millwrights understood this problem. Zachariah Allen explained in his book *The Science of Mechanics* (1829) how an engineer might measure stream flow more accurately.

"He takes the velocity of the surface of the middle of the stream, by floating a small piece of cork down it. From this experiment he calculates the retarded velocity of the bottom of the stream, and finds the medium velocity by following the following Rule. The velocity of the substance floating on the surface of the middle of the stream is taken in inches per second. From the square root of the number of inches per second he deducts unity, or 1, and then squares the remainder, which gives the velocity at the bottom, and he finds the mean velocity by taking the medium [average] between these two sums."

However you measure the flow, you can see that even small streams have lots of power. No wonder people invented ways to use waterpower to run their machines! One final question to think about: would the stream whose flow you measured be a good one for building a water-powered mill on?
Design a Mill
Calculation Tables

How many machines?

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<th># of Machines</th>
<th>Types of Machines</th>
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How much power?

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How did you derive at the amount of power and number of machines you could run?

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
How many workers do you need?

**Female Workers**

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**Male Workers**

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**Total Employees - ____________**

**Pay Day – Calculate the cost of employees per day**

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<th>Job Category</th>
<th>Wages per day</th>
<th># of each</th>
<th>Cost Per Day</th>
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**Total Daily Wages**

**Total Weekly Wages**