Project Guide

Clock Project

Given a 12V coffee grinder motor, a manual on mechanical movements from 1898, a wide range of junk and a laser cutter, students must create a working clock. The only other stipulation is that it can't resemble a normal clock. The project brings in some history (how timekeeping changed societies), design skills, math, mechanical engineering, CAD, and laser cutting skills. It's a long project – this one took the better part of two months.

Riverdale's Learning Research Team made a **short film on the project** (password: **LRT005**)

Learning goals and skills:

- Understand gear ratios
- Understand torque, how gears and other mechanical movements work
- Understand basic electrical circuits
- Use woodshop tools, learn to solder electrical connections
- Learn about the history of timekeeping – why was it important? How has it changed the world?
- Learn about the history of mechanical innovation and its effects
- Learn to use 2D CAD (we used gravit.io and occasionally Adobe Illustrator) to design, edit, and size mechanical parts
- Get comfortable using a laser cutter
- Learn, most likely the hard way, to plan carefully and think through your designs.

Facilities and tools at a glance:

- Laser cutter
- Basic wood shop
- Computers with internet connections

Materials at a glance:

- Gear motors
- Laserable wood and/or plastic

Method

While there is some theory and skill development at the beginning of this project, the projects themselves end up taking over. Most students got pretty obsessed with their clocks and the teachers acted more like coaches.

We start with a discussion about the history of timekeeping. See if students know or can guess how the earliest clocks worked (water, sun). Why was timekeeping so important? (religion, sea navigation) How did it change the world (allowed the industrial revolution to happen) etc. Look at some early design problems (e.g. at a time when clocks all used pendulums, what needed to be invented to make clocks work on the moving deck of a ship? Springs). Look at different ways to tell time from Chinese water clocks and sundials to the present. Include wacky examples. Brainstorm ideas and start sketching.

First shot at design process – identify your user and think about user's needs. Think, sketch, adjust.

Introduce **geargenerator.com** and how gear ratios affect speed of rotation and torque.

A gear ratio is the *number of teeth of gear* 1 : *number of teeth of gear 2*.

10:5 goes 2x fast, 1/2 times as much torque. Easy to demonstrate with lego gears or in our case, some laser cut demo gear sets.

Learn the different ways gears are measured:

- *Diametral pitch*: distance between teeth (length of arc). Must be same for all gears that mesh. In inches, 1 is a good value to use.

- *Number of teeth*: number of teeth on gear. this and circular pitch determine diameter.
- *Pressure angle*: determines shape of teeth. 20 degrees is a good value. Must be same on all meshing gears.

Introduce **507movements.com** and talk about the time period it's from – turn of the previous century – near the end of a period when many thought most important technology had been invented already. Explain how the index works – you can look up 145 year-old mechanical solutions – many of which haven't changed – that fit specific needs. Show students how to grab images of mechanical parts and save them for live tracing in Adobe Illustrator to use them as templates for laser-cut parts.

For wooden gears and parts, we use the 5/16″ thick 24×48″ floor underlayment pieces that Home Depot sells precut, and cut them down to 20×24″ for our laser cutter. Take care not to make the gears too small (our minimum is 12 teeth with a diametral pitch no larger than 3) or too big – wooden gears much bigger than a frisbee tend to warp. Plexiglas doesn't warp, looks cool, but is a lot more expensive and slower to cut than wood.

Once students have made gears using geargenerator, show them how to export eaech gear as an .svg and open them in a 2D CAD program (gravit.io, which is free, in our case. Inkscape, also free, works too). Go over editing shapes and the output format for the laser cutter.

Preparing a gear for laser cutting

The object imported into gravit or Illustrator is a set of grouped objects. Ungroup them, delete the red dot, the text, and the two outer rings (save the inner blue ring). Set the fill color to none. Centering on the crosshairs, draw a circular shaft hole of the diameter of the shaft you'll be using. It's a good idea to group the shaft hole with the gear outline so it doesn't accidentally move off center. Delete the crosshairs. Set the stroke of the gear outline and the shaft hole to .001″ (or whatever your laser cutter requires for cutting). Note that in gravit this will cause the outlines to disappear unless you go switch to “outline view” in the view menu. Finally, hide the layer with the blue ring. Your gear is ready to be laser cut.

The idea is to space out all your needed gears on a sheet (or two) and cut them all at once.

Getting gear spacing right

Now it’s time to laser cut the backing plate with correctly spaced shaft holes so that the gears mesh properly. Paste the gears into a separate document and unhide each gear’s blue ring. The tips of the teeth of two meshing gears should just touch the blue ring. If this isn’t just right you can have additional friction, jamming, or skipping. It is worth getting right. Once the gears are arranged, ungroup them from their shaft holes and delete them so that only the shaft holes remain. Now you can laser cut the holes.

Custom parts

Illustrator’s live trace function is a good way to convert line drawings to vector objects. We’ve had some luck with this bringing in screengrabs from 507movements and mechanical drawings found online. Students can also create custom parts by modifying geargenerator objects or building from scratch using either gravit or Illustrator.

Construction

Work on design sketches that include measurements and gear ratios. It’s a jump for some students to leave the tidy on-screen world and enter the physical, where things don’t always work as nicely as they do on-screen. Many of our students assume that once they have their gears ready for cutting they’re almost done. They’ll soon find out they’ve only begun. Having them sketch an overhead view that shows how gears are aligned and mounted is a good first step. There will be countless details to consider, including how to attach the first gear to the motor shaft. At some point a student will realize that it probably needs a custom shaft hole with a spline or a flat edge…

Once the sketches have turned into plans, the building / testing / redesigning process begins.

At the end of the project we display the clocks in public as an art exhibit.

Assessment:

- Quick quiz on gear ratios and torque
- Quick practical exercise/quiz – make a gear with certain specs in geargenerator and prep it in gravit
- Participation and final product
- Reflection at end of project

Gotchas

- Placing meshing gears just the right distance apart is key – too close and they lock up, too far away and they can skip
- Thin plywood may warp, rendering it useless for gears. Store it flat with a heavy weight on top of the stack.
- Cheap gear motors are rated at a certain speed (rpm) but in practice the speed varies, which isn't good for accurate timekeeping. This doesn't need to matter, in fact it adds a challenge to the project: students must figure out how to accurately measure their motor's speed and base their calculations on that. A variable speed circuit that adjusts voltage within a small range would also be useful.
- We often had a bottleneck at the laser cutter when students

used slow-cutting materials (acrylic or thick wood) or engraved hi-res designs. Long engraving jobs should be done at lunch or after school, not during class.

- Students often tend to rush to construction without enough planning. Try to minimize this.
- Structured as above, this is a long project. It took us the better part of two months, meeting 4x a week for 45-minute periods. It would go faster with fewer, longer periods, as it takes a bit to get set up, get back into where you were when you left off, and then clean up.

For photos, see lindylabs.org. For questions and comments, jmerrow@riverdale.edu