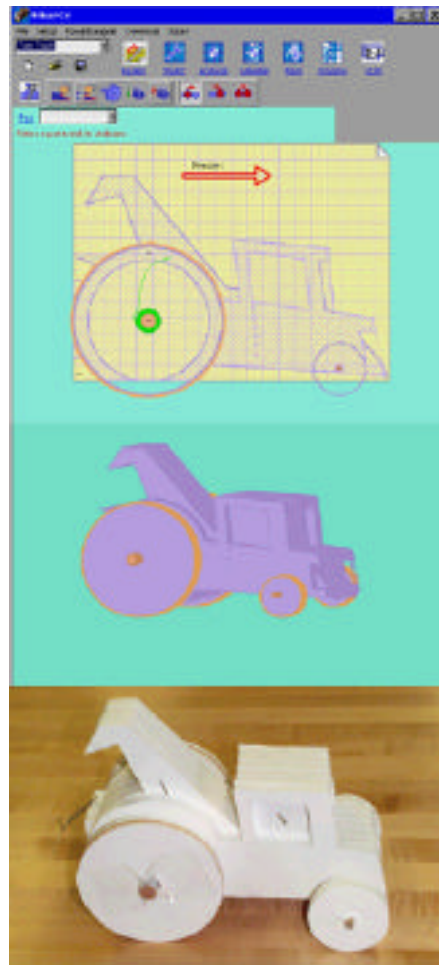


Virtual Car

Courseware for Engineering Design Education

Instructor Manual

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Virtual Car Instructor Guide

Virtual Car allows students at almost any level to design, simulate, and rapidly construct and race small model cars. It adopts the spirit of *virtual prototyping* (representing and simulating prototypes in software) and *rapid prototyping* (rapid generation of working prototypes) to bridge the gap between analytical modeling and prototype building. Using only an ordinary printer and common, readily available materials, *Virtual Car* provides a fun and absorbing hands-on activity that stimulates team problem solving, provides a strong physical context for related lessons in physics and mathematics, and introduces students to modern engineering techniques.

This document introduces the philosophy of the Virtual Car courseware and describes observations, experiences, and strategies that will be of use to any instructor who implements the project for the first time. Preparatory information such as material sources, cost estimates, and alternate materials are also documented, and suggestions for use of the courseware in various alternative instructional settings are provided.

For a broad overview of the courseware, one may also refer to the informational brochure that was prepared for Version 2.0 (<http://virtual-car.org/vcbrochure.pdf>) or the NEEDS Premier Award Submission Package (<http://virtual-car.org/VCSubmissionPackage.pdf>).

Contents

This document covers six topics:

- Background and philosophy
- Facilities (classroom, computers, equipment)
- Supplies
- Use of the courseware
- Lesson planning
- Troubleshooting student designs

This document and other instructional materials can be found at:

<http://www.virtual-car.org/>

The software is stored in a zipped file of about 500K.

A recent implementation of the courseware can be observed by visiting the ENGR 100 course web page at the University of Washington:

<http://students.washington.edu/safoutin/engr100/>

Background and Philosophy

Engineering designers engage in activities natural to the solution of open-ended problems, such as information gathering, modeling, prototype testing, and so on. To provide students an authentic experience of this function in a project-based course, the following things should be true:

- *Course projects possess visible applications for science and mathematics principles.* I find that many students come into the course expecting to simply build what seems like a good idea and test it, resisting analysis to the end. Projects must have clear connections to math and science if the role of analysis in design, and the purpose of math and science courses, is to be understood.
- *Students may apply these principles directly to their design decisions.* The most common shortcoming of existing projects is that visibly relevant principles cannot be practically applied within the scope of the project. For example, in our bridge project, we introduce the students to truss analysis, but ultimately they have no hope of actually using it to guide or evaluate their design.
- *Students may see the results of their decisions, and react to them.* Time constraints should not begrudge students the payoff of building their designs. The transition between design and construction should be as seamless as possible so that these two apparently distinct activities are understood as components of a broader design process, and students can go back and forth freely between the two.

This backdrop provides a template for students to build a picture of what engineers do, and puts them well on their way toward developing the mental discipline of the professional. But it is important to ensure that this foundation will continue to grow, by priming the students' concept of learning as a lifelong process. For example, the methods by which design is carried out are changing rapidly and dramatically. By the time these students get their first job, design professionals will be constructing parametric solid models and "virtual" prototypes [1] as naturally as they use a pencil. These technologies are being leveraged even further by rapid prototyping and 3-D printing equipment [2] that can quickly "print" testable prototypes on demand. These developments are instructive because they vividly illustrate the fluid nature of the engineering profession. They also appeal strongly to the student imagination.

If the spirit of virtual and rapid prototyping could be brought to an educational design project, it would not only emphasize the dynamic nature of the profession, but also bring modeling squarely into the student decision process, and allow for frequent transitions between the theoretical and the physical. As a result, students might achieve a clearer view of the underlying objectives and constraints of the design problem, and of the scientific principles that apply. The *Virtual Car* courseware is an example of this approach.

Bringing the spirit of virtual prototyping into an educational context called for a design problem that could be modeled realistically with simple software, rapidly prototyped without special equipment, and built out of ordinary materials. This led to the concept of the *virtual car* -- a small toy car of a specific construction that is adapted to these constraints. It has a built-up, layered construction of a relatively thick sheet material such as cardboard or foamcore, and is powered by a wind-up spiral plastic spring fashioned from the plastic walls of an ordinary PET (polyethylene terephthalate) soda bottle.

The *Virtual Car* software is a simplified virtual prototyping application adapted exclusively to the design of these cars. Suggestive of professional virtual prototyping software, it provides a more bounded environment. Students design the car interactively and can immediately see the effect of their choices on key performance metrics such as traction, propulsion, speed, and

distance. When a physical prototype is desired, the software generates paper templates that can be used to build a faithful working model.

The Virtual Car courseware is designed to address the following broad learning goals:

- *Students form a clearer picture of what engineers do.* This includes:
 - Recognizing the class of problems that engineers are concerned with (design)
 - Becoming aware of contemporary tools and approaches.
- *Students begin developing the mental discipline of the professional designer.* This includes:
 - Understanding design problems abstractly in terms of objectives and constraints
 - Identifying principles and relationships that govern the problem
 - Making effective use of teamwork and communication
 - Approaching design as an ordered process.

The courseware pursues these learning objectives through the following strategies:

- *Highlighting applications of math and science to the design problem*, via concepts and relationships that are easily grasped and can be applied directly to design decision.
- *Bridging the gap between designing and building*, allowing students to transition between both activities bidirectionally and begin to understand them as components of a common process.
- *Emphasizing the design problem itself*, by reducing the attentional burden of repetitive calculations and the labor burden of fabrication, which carry little educational value.

Although the primary target audience has been freshman-level engineering students, the courseware is designed to be adaptable to many educational levels and contexts.

Adaptable Learning Objectives. A Virtual Car project can be tailored to many different levels of learning objectives. For example, when it comes time to select materials, students may simply be provided materials and their physical properties, or be asked to come up with their own choices, procure them, and measure their properties independently. In more advanced settings, the task could be enriched by asking the students to list the functional requirements of each material to help justify their choices.

Adaptable Project Duration. Virtual Car can provide the basis for anything from a one-day activity to a multi-week project involving multiple prototypes and competitions. In ENGR 100, the courseware is typically used throughout a five-week project but has also been employed in single-day exercises. The design and construction of a virtual car can be achieved in as little as two class hours. Omitting the construction phase and instead using the virtual race mode will save even more time.

Disciplinary Emphasis. Many opportunities arise to investigate certain issues in more detail, or to jump off into related topics of design and science. For example, the plastic spring provides a context to discuss the manufacture of soda bottles, the thermosetting properties of PET plastic (useful for heat-treating the spring!) and the functional requirements of soda containers. Topics fall within many engineering disciplines, making it amenable to truly multidisciplinary project settings, including elements of mechanical engineering (performance), industrial engineering (assembly), chemical engineering and materials science (plastics), and mathematics (spring windage calculations).

Facilities

Naturally, each student team will require access to a PC computer to design the car. If they will also be constructing a prototype, they will also need to be able to print the templates. During the assembly process, students should have plenty of desktop space to work with board materials and do parts cutting and assembly. Desktop surfaces should be covered with a masonite or hardboard sheet to prevent damage from knife blades.

Depending on the thickness of the construction material and the width of the spring (which determines the width of the car), there may be a large number of templates to print, so make sure the printer is well stocked with paper. Printing a full set will require one sheet per layer, plus two to four sheets for the wheel templates. If paper is in short supply, students may instead print single copies of the outer and inner layer templates and re-use them for cutting out each template.

A PC overhead projector is very useful for demonstrating the software, displaying virtual races of student designs, and for student presentations.

Supplies

The table below shows the recommended supplies and their application:

Material	Application
Foamcore, cardboard	Car body and wheels
Plastic soda bottles	Spring engine
Wooden dowels	Axles
Rubber bands	Wheel treads
Paper glue	Body assembly
Plastic tape	Spring assembly
Paper clips	Spring installation
Equipment	
Hobby knives, scissors, pins Laboratory or postal scale (optional) And, of course, a PC and printer	

For the first-day construction of the sample vehicle, the following items should be assembled into a car-building kit, distributed one to each team:

1. A set of pre-printed templates for one of the standard Virtual Car designs (Default design, Racer, Tow Truck, Pickup, or Wheelie).
2. Four X-Acto knives
3. Scissors
4. Rubber bands (for wheel treads)
5. One plastic 2-liter soda bottle made of PETE plastic
6. One 1/4" and one 1/2" wooden dowel, 7 inches in length
7. Plastic tape (for spring splicing)
8. Several paper clips
9. Thumb tacks (for attaching spring to axle)
10. Paper glue (for gluing templates to construction board prior to cutting)
11. One 20" x 30" sheet of 1/2-inch foamcore
12. Upholstery pins (1.5 inches to 2 inches long) for registration of layers

Half-inch foamcore is a good all-around board material. It is available in many office supply and craft stores in sheets ranging from 20 x 30 inches to 30 x 40 inches.

One 2-liter PETE soda bottle provides a strip that is about 6 inches by 13 inches, which is enough to make a 2-inch-wide spring that is 36 inches long, or a 1.5-inch spring that is 48 inches long.

Use of the Courseware

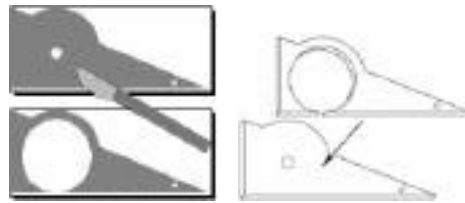
Interactive Design

To begin designing a Virtual Car, designers first consider possible construction materials. Several common materials (foamcore, wood axle, and plastic spring) are already defined in the software for those who want to start designing right away. Custom materials may be defined by measuring their physical properties, such as density and thickness, and entering them into the software. Designers are then free to generate virtual designs by specifying variations of key design parameters, such as body shape, material choice, wheel size, spring dimensions, and type of drive (front, rear, or all-wheel). Four default car designs (illustrated in Appendix E) are available to get started.

Each variation of design parameters represents a design alternative that can be instantly modeled for performance. Modeling takes place in several user-controlled steps. First, a 3-dimensional rendering of the design is drawn in a layer-by-layer fashion suggestive of 3-d printing. Students can step through the building process at their own pace to inspect internal features of the design. Next, Virtual Car computes and displays resultant quantities such as total mass, center of mass, overall dimensions, propulsive forces, and normal forces on the front and rear wheels. Finally, an animated simulation is performed showing the effect of acceleration on normal forces and traction. Performance measures such as speed, travel time, distance traveled, and the possibility of skidding are displayed. If multiple designs have been defined, they can be tested against each other in an animated "virtual race".

Rapid Prototyping

After identifying a virtual design that promises good performance, the designer may print it to an ordinary printer to produce a "paper prototype", a set of parts-cutting templates for layer-by-layer construction of a working model from sheets of the specified materials. The illustration shows two templates: an outer wall, and an inner layer (the round core is where the wind-up spring resides).



When cut out and stacked, the layers form a physical instantiation of the virtual prototype. This construction method standardizes and simplifies the construction process, and ensures that the physical version is as faithful as possible to the virtual version. Foamcore and corrugated cardboard are excellent materials and can be cut with X-Acto knives. An inexpensive benchtop band saw, while not essential, allows many other materials to be used.



Construction

As construction nears completion, design teams transform into pit crews as they begin troubleshooting the many unanticipated problems that invariably occur when the newly-built car hits the track. Team members cooperatively problem-solve as they brainstorm among themselves to identify the source of the problem (friction, slippage, misassembly) and implement solutions on the fly. Students thereby distinguish problems of implementation from problems of design.



Redesign

When attention refocuses on improving the design, the relatively small number of design parameters leads to an enormity of possible variations. Virtual Car provides features designed to aid the redesign process, such as Power Designer mode, which systematically varies selected design parameters, and Virtual Race mode, in which alternative designs compete in simulated races.

Lesson Planning

Virtual Car is the basis for a freshman design project that is taught in Engineering 100, Introduction to Engineering Design, at the University of Washington. Each section of ENGR 100 includes three group projects: a bridge-building project, an engine dissection project, and a final project chosen by the section instructor from a pool of four alternatives. The Virtual Car project is one of the alternatives, and the project is typically taught over a four to five week period. In this context it has been used in individual homework assignments and in-class exercises, by students designing individually, designing as part of a group effort, and by groups of students interacting with the software collectively.

Format

The Virtual Car project is normally assigned as a group assignment, with students assembled into teams of three to five. This provides plenty of fuel for brainstorming and cooperative problem solving, and plenty of labor for the construction phase, when parts must be cut out. If students are assembled in smaller groups or are working individually, it will take longer to cut the parts. Of course, the construction phase can be omitted entirely if desired. In this case, it is appropriate to assign the project as an individual project of shorter duration.

Schedule

The following schedule has proven successful for groups of three to five students. Each day in the schedule represents a two-hour class period.

<p>Day 1 Discussion: Introduction Activity: Build default design</p>	<p>Day 2 Activity: Finish construction, race Discussion: Relative performance</p>	<p>Day 3 Discussion: How the software works Activity: Practice designing</p>
<p>Day 4 Activity: Material properties measurement</p>	<p>Day 5 Activity: Conceptual design</p>	<p>Day 6 Activity: Final Design</p>
<p>Day 7 Activity: Construction</p>	<p>Day 8 Activity: Construction</p>	<p>Day 9 Activity: Preliminary Competition</p>
<p>Day 10 Activity: Redesign</p>	<p>Day 11 Activity: Redesign</p>	<p>Day 12 Activity: Redesign</p>
<p>Day 13 Activity: Presentation</p>	<p>Day 14 Activity: Final Competition</p>	

Suggested Schedule

For more details regarding class activities and homework assignments listed below, refer to the ENGR 100 web page at <http://courses.washington.edu/engr100/> or to the resource page at <http://virtual-car.org/>.

Day 1:

Discussion:

Introduction to virtual prototyping, rapid prototyping, and the virtual car concept. Discussion of competition format and rules. Assemble teams.

Activity:

Distribute car-building kits to the teams, and begin construction of one of the sample vehicle designs. Each team should build a different sample design (Default, Racer, Tow Truck, Pickup).

Day 2:

Activity:

Finish construction of the sample vehicles; have teams race each other and note differences in performance among the different sample designs.

Discussion:

Note differences in performance and hypothesize reasons for the differences. Were they design differences or craftsmanship differences? What specifically caused some vehicles to go slow while others went fast?

Assign Homework #1, "Material Ideas", in which students consider materials that could be used to build the car. Teams are to bring in sample materials for Day 4.

Day 3:

Discussion:

Demonstrate calculations performed by the software, including weight distribution, center of mass, summation of moments to determine normal forces on each wheel, traction calculation, propulsion, and so on.

Activity:

Students work in teams to begin car design for preliminary competition.

Assign Homework #2, "Your Personal Design".

Day 4:

Students bring in sample materials and measure their properties (density, thickness, etc).

Day 5:

Conceptual design; students enter new materials into software and consider alternative car designs.

Assign Homework #3, "Traction"

Day 6:

Final design; students begin to finalize their design for the preliminary competition.

Day 7:

Students print templates for construction and begin cutting out parts.

Assign Homework #4, "Distance"

Day 8:

Construction continued.

Day 9:

Preliminary competition

Day 10, 11, 12:

Redesign

Day 13:

Team presentation, discussing performance in preliminary competition and how the team plans to improve in the final competition.

Day 14: Final competition

Troubleshooting Student Designs

General rules and relationships

- The wider the spring the more torque, but the more likelihood of skidding
- The longer the spring, the greater the distance.
- The smaller the drive axle diameter, the greater the distance.
- The greater the wheel diameter, the lesser the propulsive force, thus reducing skidding; but the slower the car.
- If the car skids, either reduce the spring width, or increase the drive wheel diameter.
- An over powered car will simply turn a pirouette on the starting line.

Car won't go, or goes very slowly

All of the standard designs should go 14-15 feet if properly assembled. Here are some of the reasons a car might not go that far, or at all:

- The coiled spring is rubbing against the inner walls of the spring chamber, because it was cut a little too wide.
- The spring has become detached from the axle.
- There is too much friction on the non-drive axle. The wheels should spin freely on the axle, or else the axle should spin freely within the body.
- The rubber bands that are used to attach the wheels to the axles are rubbing against the body.
- The spring is coiled the wrong way. The spring naturally wants to coil in one direction, but when installed in the car, it should be wound in the other direction, or else it will provide no power.

Car curves in one direction or the other

- The drive wheels are slipping on the drive axle. If one wheel loses propulsion this way, the other wheel makes the car turn in its direction. The simplest way to attach the wheels firmly is to wind a rubber band around the axle on each side of the wheel, so as to pinch the wheel between the rubber bands.
- Wheels are slightly different sizes
- Wheels are out of round, so that one wheel tends to provide more propulsion than the other, or the car bounces around too much.
- The tread is not getting enough traction, because the car is too light to produce enough normal force(weight) on each wheel to provide a predictable reaction to the propulsive force. So, the wheels spin, and owing to the variable nature of the contact between each of the two wheels connected to the axle that is spinning, you will get variable propulsive force on each side, causing the car to go to one side or the other.