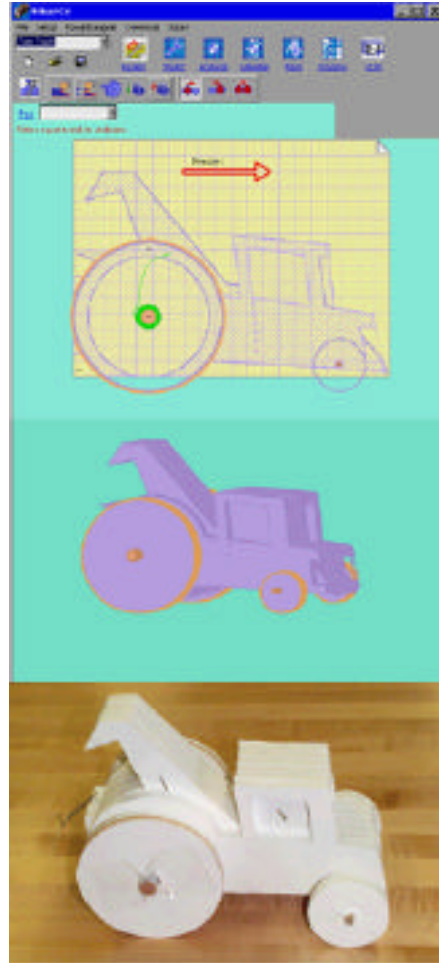


Virtual Car

Courseware for Engineering Design Education



2001 Premier Award Submission Package

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Virtual Car

Virtual and Rapid Prototyping in the Classroom

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.

The courseware is for use on Windows-based platforms and has been entered into the NEEDS database. A web site has been set up for convenient access:

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

The software and accompanying material 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/>

Michael J. Safoutin is the sole author of *Virtual Car* and of all related instructional materials. As a graduate appointee he is allowed by University of Washington copyright policy to retain all copyrights. He authorizes NEEDS to become a non-exclusive distributor of the courseware, as submitted, for the 2001 Premier Award competition.

Sincerely,

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Virtual Car

Virtual and Rapid Prototyping in the Classroom

Background

For five successive quarters I have taught a popular freshman-level engineering design course at the University of Washington. In it I often relate memories of my own undergraduate education, which was characterized by a persistent mystification about what practicing engineers actually do. This story always resonates with the students -- they are taking the class precisely because they are seeking the same understanding. They expect to acquire it by doing hands-on, team-based design projects over a ten-week period. Lectures, guest speakers, and theoretical solutions that go unbuilt are of limited interest to this audience, who are seeing enough of that in their other classes.

So what *do* engineers do? Engineering *designers*, at least, engage in activities natural to the solution of open-ended problems, such as information gathering, modeling, prototype testing, and so on. They pursue these tasks with an acquired mental discipline, motivation, and approach that is the result of their education. But students enter this class motivated by recommendations of advisors, anecdotes of engineer relatives, or images conveyed by the media. An introductory course is faced with building upon these initial motivations by providing sight lines toward more realistic images of engineering practice. For a project-based course to do this effectively, I feel that the following things must 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. I also find that they 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.

Description of the Courseware

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.

Instructional History

Virtual Car is the basis for a freshman design project that has been taught for five successive quarters of Engineering 100, Introduction to Engineering Design, at the University of Washington [3], [4]. 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 has been used in one of the four sections offered each quarter. When it debuted in Winter Quarter 2000 it was an instant success, and since then has become a popular feature of ENGR 100.

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. Since its introduction, a total of at least 160 students have used the courseware (32 students per quarter), with plans to continue using the courseware in future quarters.

Learning Goals

The Virtual Car courseware is designed to deliver the following broad outcomes:

- *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.

Instructional Strategy

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.

The Learner Experience

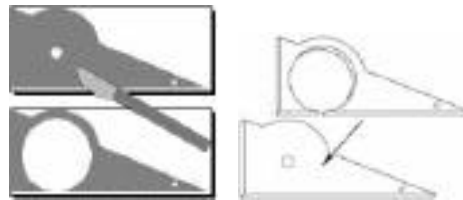
Interactive Design

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.

Instructional Settings

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).

Supporting Materials

Lesson Plans

Lesson plans for a freshman-level engineering course are available at the ENGR 100 web site. These documents are in HTML format and contain suggested homework assignments, discussion topics, and lecture material. Instructors are invited to use these plans as-is or use them as a base to develop their own lesson plans.

Instructor Guide

An instructor's document is available that describes the philosophy of the Virtual Car project as it is taught in ENGR 100, and lists 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. Suggestions for use of the courseware in various alternative instructional settings are also provided. For a broad overview of the courseware, one may also refer to the informational brochure prepared for version 2.0 (Appendix F).

User Guide

One goal for the interface design of Virtual Car was to make it simple enough that a typical student could use it effectively without referring to an instruction guide. Extensive use of screen hints helps users understand the purpose of every interface element. Online help is available to suggest overall strategies for achieving a good design and for applying knowledge of underlying mathematics principles.

At appropriate points in the user interface, links are provided to helpful information pop-ups that are designed to shed light on the stage of the design task currently being pursued or the simulation results currently being displayed. For example, clicking on the label that reports the current distance estimate opens a window that describes the variables that influence distance.

Evaluation and Assessment

Direct Assessment

Anonymous surveys are taken at the end of each quarter to assess the effects of the course overall and of the individual projects. Assessment data from both sources suggest that the courseware has had a particularly positive influence on learning.

Course Evaluations

As part of the departmental course evaluation, ENGR 100 students are asked to provide feedback on course content and the course as a whole. Because the final project represents the primary difference in educational content among each section (the bridge and engine projects are conducted as similarly as possible to ensure course consistency), section differences in these measures are likely to be indicative of perceptions of the final project. During the 2000-2001 academic year, sections that taught the Virtual Car project regularly outperformed others in these measures and maintained the highest averages overall. Although these sections shared the same instructor, measures of instructor contribution did not show as strong a trend.

Measure	Virtual Car (3 of 12 sections)	Other sections (9 of 12)	Difference
Course as a whole	4.44	4.04	+0.40
Course content	4.20	3.94	+0.26
Instructor contribution	4.30	4.18	+0.12

Table 1. Course evaluation scores, scale 0-5 (mean, 2000-2001).

ABET Criteria (a-k)

Students were also asked to assess their perception of course contribution to learning within each of the ABET2000 criteria a-k (form: Appendix D). Sections that taught the courseware-based project regularly received the highest ratings each quarter, culminating in the following averages:

ABET criterion	Virtual Car sections	Other sections	Difference
(a) apply mathematics, science, engineering	4.9	4.7	+0.2
(b) design and conduct experiments	5.4	5.0	+0.4
(c) design a system, component, process	5.5	5.2	+0.3
(d) function on multidisciplinary teams	5.5	5.3	+0.2
(e) identify/formulate/solve engineering problems	5.3	4.8	+0.5
(f) professional and ethical responsibility	4.8	4.1	+0.7
(g) communicate effectively	5.3	4.7	+0.6
(h) engr solutions in global and societal context	4.7	4.2	+0.5
(i) recognize/engage in life-long learning	4.7	4.3	+0.4
(j) knowledge of contemporary issues	4.5	3.9	+0.6
(k) techniques, modern tools for engr practice	5.3	4.7	+0.6

Table 2. Self-assessment of course contribution to ABET learning, scale 1-7 (mean, 2000-2001).

Project Evaluations

Beginning in Spring 2000, students were asked to rate each project on a scale of -3 to +3 with regard to four measures: enjoyment, degree of learning, effective use of class time, and degree to which it promoted understanding of what engineers do (form: Appendix C). During this period, ratings for the Virtual Car project ranked well above the project average, particularly with respect to degree of learning and degree of understanding of engineering:

Criterion	Virtual Car	Others	Difference
Enjoyment	2.3	2.1	+0.2
Learning	2.2	1.8	+0.4
Time utilization	2.3	2.1	+0.2
Understanding of engineering	2.4	2.0	+0.4

Table 3. Project evaluation scores, scale -3 to +3 (mean, Sp 2000-Sp 2001)

Other data

Gender differences. One concern when introducing a new engineering project is its receptivity among both male and female students. While gender-related assessment data was not gathered, it is worth noting that these positive results were achieved in sections having an above average female enrollment level. The courseware-based sections had an average female enrollment of 27% (ranging from 22% to 32%), contrasting with a 21% average in other sections during this period.

Response rates. End-of-quarter surveys in ENGR 100 have enjoyed a good response rate among the 32 students per section, typically ranging between 70%-100% for course evaluations and nearly 100% for project evaluations.

Written Feedback

Feedback from students is consistent with the conclusion that the courseware played a role in achieving the course evaluation results. Student comments gathered from anonymous evaluation surveys indicate that the courseware has been engaging and mentally stimulating; that learning has taken place, particularly about engineering design and the engineering profession; and that students are able to fit the courseware into its appropriate place as part of a larger design process.

Students frequently commented that they found the courseware engaging and stimulating:

"Very fun! I loved the computer aided design aspect of the project. It was fun to let our imaginations run wild on this project. I have no suggestions for improvement on this project."

"It definitely felt good to be able to draw something up on a computer and be told that it would go a certain distance at a certain speed and then a couple of weeks later be able to build that car and find that it does go that certain distance at that certain speed."

"The Virtual Car was an excellent project. I enjoyed using the software, and being able to see how changing various physical aspects of the car would enhance or hinder its performance."

"I loved this project, and this summer will be improving on my car. The only thing I would change is adding more constraints."

"The virtual car program was amazing! I was blown away by the amount of detail...it was very professional...and fun to use!"

"Best part: the Virtual Car project, because it really stretched my thinking."

"Best Part: Virtual car. It was a lot of fun to build and design the cars, and then race them against other cars to see how they perform compared to the other ones."

Other comments credited the courseware with advancing understanding of what engineers do:

"In the Virtual Car project, I learned a lot about what makes cars go fast and what slows them down. But most importantly, I learned how real engineers would go about building a car. We basically used a simplified version of their programs. I learned what sort of problems or constraints that they have, and how to get around them."

"Best part: Virtual Car! It helped me understand a lot more about engineering and how they process information to invent or make something."

"[Virtual Car] showed me the value of using a design program to maximize the efficiency of time use. By doing this, it helped me to understand how engineers use design software to make the products they produce. Building the cars and testing them was also very entertaining."

"I liked this project because we weren't just building a car, we were using the computer program to make our design like professional engineers would do."

"The virtual car project was definately the best part of the course because it actually involved some engineering."

Learning in general was also enhanced:

"Best project I ever did. Not only was it fun, but I think I learned a tremendous amount by using the computer program that was given to us."

"Virtual Car was fun because the results were actually something worthwhile and fun to do. The physics that was put into the making of the car helped in learning how cars come out into market."

At the end of each quarter, students also turn in a reflective paper addressing their experiences in the class. Excerpts from these papers show that the courseware is remembered as a positive influence on their learning, and that they have viewed the courseware as one component of a broader design process. The following passage is typical:

"The virtual car project required that we apply the various aspects of the design process. Our group applied the majority of these steps into the production of a final car. We needed to build a car capable of performing in a competition. Specifically, our objective was to build a car optimized for both speed and distance. In order to accomplish this, we first needed to gather as much information as possible. This required that we test the properties of various different materials and then enter designs into virtual car. After doing this, we were then able to compare and contrast several different possibilities. This is how we developed an initial design strategy. Virtual Car allowed us to generate multiple design possibilities. Because it was able to predict an outcome regarding the speed and distance of the car, in a sense, we were able to simulate how certain models would perform. After going through these steps, we were able to choose a specific design for the prototype car. Based on the performance of this car, we were then able to generate a final car. Throughout this entire process, our group was required to communicate and to exchange ideas."

- Erin W., Autumn 2000

Some additional passages from reflective papers are provided in Appendix A.

Discussion of Courseware Evaluation Criteria

Instructional Design

Interactivity

Creating a virtual car is a thoroughly interactive process. The drawing of the body shape, the selection of design parameters, and the simulation of the design are controlled by the student at the pace he or she desires. The software instantly responds to these user inputs by providing meaningful feedback in the form of property calculations and performance projections. Exemplary default designs are provided initially, but students can quickly turn toward making their own designs.

Hands-on design experiences are also important. When used to its fullest extent to initiate a construction phase, the courseware facilitates high quality group interaction. Between construction phases, groups frequently assemble at a computer to try new designs in the virtual environment. Students can make the transition from modeling to building, and back again, whenever they think the time is right.

Cognition/Conceptual Change

As students advance through the courseware-based project, conceptual insights form as a direct result of the courseware's design:

- **Engineering is optimization, not maximization.** Faced with a speed competition, students initially react by maximizing the power of their car. When the software predicts that the car will be overpowered and unstable, students quickly adjust their thinking toward finding an *appropriate* power level (usually *before* they have built anything).
- **Design from the bottom-up.** When it comes time to define construction materials, many students initially focus on *objects* such as cereal boxes, milk cartons, or wheels made from records or compact discs. However, the software enforces a more abstract approach that requires specifying *material types* and *forms*. At first there is some disappointment that favorite objects cannot easily be worked into the design, but by the end of the project these complaints have disappeared, and students are designing from the bottom up, thinking in terms of forms and their properties.
- **Constraints make design manageable.** Another initial complaint is that the software imposes too much restriction on the car design. These complaints cease as students explore the solution space and discover the true extent of variation in design possibilities. By the end of the course, students frequently comment that they would have liked to see *more* constraints imposed by the software, and regularly describe the project as the most *unconstrained* of the course.

Anonymous feedback and reflective papers provide more evidence that students gain deep insights from use of the courseware and become aware of the value of modeling in the design process.

Content

The courseware's content stems directly from the specific design problem it presents. For example, the lessons that wheel diameter affects propulsive force and distance traveled, and that normal force in conjunction with the coefficient of friction determines traction, are clearly relevant. These relationships are encountered and manipulated in direct interaction with the software, and in the context of solving the design problem. Students are highly motivated to discover these relationships and begin using them, because it immediately affects their design success. Links between content areas are inherent in this context. The sequencing of material is also intuitive, following the evolution of the design. The natural process of using the software reinforces the concept of a goal-oriented design progression, punctuated with frequent iteration -- a very accurate picture of real design processes.

Multimedia Use

Multimedia use is limited to the minimum necessary to enhance the user interface without distracting the user. The animated 3-D construction sequence is user controllable and can be stepped through layer-by-layer, allowing the user to carefully inspect the projected physical form and examine internal features. The dynamic simulation screen can also be incremented in a second-by-second fashion so that fluctuations in forces can be tracked. Different materials are drawn in different colors for conceptual clarity. If the student defines custom materials, he or she can choose the color in which these materials will appear.

Multiple representations do exist where appropriate. The template preview button presents a preview of templates before they are committed to paper. All design parameter settings can be printed on a sheet for reference or documentation. Where applicable, parts can be sized by either dragging the mouse or by typing numbers into an edit field.

Instructional Use/Adaptability

Sample lesson plans and an instructor document are available, including assessment suggestions. Online help is stored in ordinary HTML format so that instructors may make modifications to emphasize the details of their own lesson plans. While the software makes it possible to create physical prototypes, this step is optional and a large amount of value can be gained from racing student designs in virtual race mode. The minimal computing requirements, and the low cost of construction materials, allow the courseware to enrich a broad spectrum of educational settings.

Software Design

Engagement

The courseware harnesses the natural desire for instant gratification. The ability to generate an instant 3-d rendering of a 2-d representation is very appealing, and students tend to work hard on the 2-d drawing, hoping to be proven "right" when the 3-d rendering is generated. The instant projections of mass and performance are also interesting and engaging, and encourage frequent iteration and exploration of "what-ifs".

Learner Interface and Navigation

The various modes through which the virtual prototype is taken are based on the natural progressive stages of the design process. Each button-activated mode corresponds to a natural design state: drawing, visualizing, analyzing, simulating, and building. This navigation sequence is reinforced by the theme of the button icons, which suggest a progression from a sheet of drawing paper, to a sequence of virtual screens, and back to a sheet of paper representing the construction templates. No scroll bars are necessary.

Technical Reliability

Virtual Car has undergone two major revisions since its debut in March 2000 and its underlying code is the result of dozens of student-discovered bug fixes and design suggestions resulting from extensive classroom use. Due to its heavily object-oriented design and its use of the Borland Delphi rapid application development tool, Version 3.0 and subsequent versions should retain the stability of previous versions. Virtual Car 3.0 has been tested on Windows 95, 98, NT 4.0, and Windows 2000. The software also performs reliably on systems having hardware limitations such as small screens and limited memory.

Engineering Content

Accuracy of Content

The physical principles and relationships that govern performance prediction for these cars is well known and well understood. Center of gravity, normal forces, tractive capacity, acceleration, and accelerative weight transfer are calculated by textbook procedures. The accuracy of the projections have been borne out by several quarters of actual use. Calculations are documented in the appropriate online help links.

Organization of Content

Topics are presented in the form of a real design experience, not as sequential lessons. At any point, the user can click on a help button associated with a particular projection or calculation and view a page that outlines the physical principles behind the calculation and how it was performed.

The choice of the *English system* as the courseware's unit system deserves comment. This decision results from the fact that in the US, almost every form of construction board, wooden dowel, metal rod, paper product, and other construction material that the student will encounter is denominated in *inches*. The strategy is twofold: to reduce the distraction of unit conversions, and to allow the student to discover that these "nominal" sizes often differ from measured sizes. Future versions will include a metric mode for international compatibility.

Consistency with Learning Objectives

The learning objectives of the courseware are carried out through interaction with the software, which represents an authentic design process and culminates in the fulfillment of a projected performance. This experience is instructive in itself, and requires little if any pre-existing science or math knowledge to appreciate. More advanced audiences will see connections to math and science courses that they have taken or are currently taking. The depth and breadth of instruction is just right for a broad spectrum of audiences -- it expands into, but is not limited by, the curiosity and educational level of the user.

Conclusions

The Virtual Car courseware adopts a highly unique approach that integrates analytical modeling with physical construction to allow students to experience both aspects of the design process in a way that is as bidirectionally integrated as possible. The courseware grew organically out of the normal continuous improvement cycle associated with a long-running freshman design course, and has been associated with very positive educational results. There are indications that the courseware would be equally effective in many other educational settings.

The context in which it was developed does not provide a means for significant dissemination to the greater educational community. Organizations such as NEEDS provide an important service by drawing attention to quality courseware and providing a distribution path for courseware that otherwise might not be distributed to its fullest possible extent.

Acknowledgements

I would like to acknowledge the encouragement and support of the staff of the Center for Engineering Learning and Teaching (CELT) and the College of Engineering during the development of this courseware. As a graduate appointee at CELT under the guidance of Director and Professor Cynthia Atman of Industrial Engineering, I developed an appreciation of current educational research issues and methods, and the importance of bringing what we discover into the classroom. Professor John Kramlich of Mechanical Engineering provided the opportunity to begin practicing these skills as an instructor of ENGR 100. Dr. Jennifer Turns of CELT developed the format of the project evaluation surveys and allowed me to adapt it to ENGR 100. Mary Cook of the College of Engineering provided the opportunity for instructors to develop new course projects and encouraged the persistent collection of assessment data. Finally, the students of ENGR 100 provided daily encouragement and countless suggestions that have made a tremendous impact on the quality of the end product. All of these influences combined to make the courseware possible.

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Appendix A: Excerpts from Reflective Papers

"The virtual car software was very helpful in designing the car because we could not decide how the car was going to look, how much weight was too much, and just didn't know how each characteristic of the car changed the performance. After playing around with the program we saw exactly what the shape, for instance, does to the overall performance on speed and distance. Without the calculations that the car software made we would have had no idea how our car would perform until we actually built it and raced it. By using the program we learned that the spring length was not nearly as important as the width in the speed competition and that bigger wheels may decrease the likelihood of skidding, and smaller wheels will go faster. Without the program, though, who knows how small is too small and how much weight is too much."

- Darrin M., Spring 2001

"Going through the class, we got to experiment with the software called "Virtual Car" which I considered very useful because we were able to test our car before making it. The software saved us time and helped us to see our car shape in 3-D to provide us with a realistic feeling of the car. Also what I liked is that we had fun making a car out of nowhere and see our results because with the software, we were able to test and run our car without even making it."

- Huy H., Spring 2001

"This assignment was my favorite, because what we constructed was completely ours. We saw a few examples from previous years and we made a default car, but from that point on, we were on our own. We used the Virtual Car software to design our car. We just kept running new designs through the program and saw how they would hypothetically fare. From the software, we could conclude what changes had the greatest effect on the speed of the car. We decided that the weight of the car, the friction of the wheels to the floor, the size and type of the spring were the most important factors in how the car would compete. We decided what kind of material we wanted to use, and then later decided that we wanted to use a composite material of balsa wood and foamcore. We made the back wheel much bigger than the front wheel, the spring longer and wider, and the ratio between the size of the axle and the wheel very large. From these small alterations to the default car, we made our car go faster and farther. Also, our car ended up being lighter than the default car, which helped some too. In this project I learned how to put everything I knew together."

- Stephanie T., Winter 2001

"The software we used to first design our cars was very useful. I found myself looking through the computers one day during the Engine Dissection project and I came across it. I played with it a little and as we started the virtual car project I felt that I had a definite advantage just for having looked at it before... I think the software did give us a good feel of what it is actually like to generate a computer prototype, test it, and then build it."

- Josh M., Spring 2001

"In my opinion, the virtual car project was by far the most fun and interesting of all the projects we did this quarter. Before this project I had never considered how engineers prototype their designs. Now I have a very clear understanding of the types of things engineers can design and test without really spending much time constructing them. My favorite part of this project was seeing how close we could get our car's performance to match the specification the virtual car software computed for our design. Surprisingly, we were able to get our car to travel at almost exactly the same speed as the program estimated. Since I plan to make my career in engineering, the knowledge I gained about rapid prototyping in this project could easily prove to be very valuable. I found the virtual car software to be very helpful. In fact, it was not only helpful, it was very interesting. I felt that it was very easy to use and gave us a lot of freedom in designing our cars. The virtual car software helped me understand the importance of virtual prototyping. I feel that this is a concept that will be very valuable in my career as an engineer."

- Peter C., Spring 2001

"I loved the virtual car software, and thought it was extremely helpful. The fact that it gave an idea about speed and distribution of the weight needed was great. These were my two favorite aspects. The software also helped me to greater understand what engineers do. I felt that I learned more about the process of design. Without the software I think I would have been able to come up with a working car, but because of the software I knew that our group's car needed more weight in the front before the problem arose. This made it so we could change the body to make the car more effective, instead of needing to add weight later."

- Bree A., Spring 2001

"Designing the virtual car was my favorite of the projects we did. After racing the first basic car, our group set to work identifying the objectives and constraints of the design, and the criteria the design needed to meet. We gathered information, planned, and generated possible ideas for a car design before settling on a plan. Other successful car models were analyzed and used to aid the selection of a design. We communicated with each other a great deal, as we each worked on parts of the car, and scouted hardware stores in search of materials that would improve the car. We used the virtual car program to estimate how the car would perform, and a prototype. Our prototype was fairly basic because we did not want to release any of our winning ideas to others."

- Holly G., Autumn 2000

"From this project, I came away with a much better understanding of the design process. Since I had the chance to work with the Virtual Car software to create a design on the computer and see how it would perform before I ever built it gave me a better feeling of how engineers in real life work with computers to develop models on the computer. I know now I have a much better understanding of the design process and can use it later in my life as I continue to better my skills in the fields of engineering. Once I understood the concepts that the program used to determine the distance and speed of the car, it became much easier for me to use. It helped the design process immensely because we did not have to build trial car after trial car. We could design the car on the computer and then be very confident that it works out very similar to the predictions in real life. I can't think of any more possible additions to the software that could make it better."

- John K., Spring 2001

"The last project that I worked on in Engineering 100 was the virtual car project. In this project we went over every design step. We first recognized what the design was supposed to serve, which was to design a fast and/or long distance running car. We then identified our constraints by looking at the directions on the Engineering 100 web page. Next, we gathered information using the virtual car design software. We entered in the materials that we were going to use, and the program gave us an exact distance that our car was supposed to travel. During the planning process we decided on what we wanted to focus on. We had a choice between a speedy car and a car that could travel a long distance. We decided to go for a car that would succeed in both categories.

"The management step came into play when we built our prototype. The front wheels were crooked because the hole that was drilled in the front for the dowel was crooked. To fix this we re-drilled the hole to straighten out the wheels. We also played with virtual car, creating different designs until we saw one that we liked. This helped us out in the idea generation step and the modeling step. We then agreed on a design and started building our prototype. After building the car we then raced against other groups to see how our car performed and how others' performed as well. The virtual car project has proven to me that the design process plays a crucial part in designing."

- Barry C., Autumn 2000

Appendix B: Letters of Support

Attached:

(1) Letter from Dr. Cynthia J. Atman, Director, Center for Engineering Learning and Teaching (CELT); Associate Professor of Industrial Engineering, University of Washington.

(2) Letter from Mary Cook, Course Coordinator for ENGR 100, College of Engineering, University of Washington.

Appendix C: Project Evaluation Survey Form

For these questions, please use the ratings below:

- 3 = I strongly agree with the statement
- 2 = I agree with the statement
- 1 = I slightly agree with the statement
- 0 = I neither agree nor disagree with the statement
- 1 = I slightly disagree with the statement
- 2 = I disagree with the statement
- 3 = I strongly disagree with the statement

a. **I enjoyed it.** Please circle the number that indicates the extent to which you agree with the statement "I enjoyed it" for each project.

PROJECT	I Enjoyed It						
	agree						disagree
Bridge Project	3	2	1	0	-1	-2	-3
Engine Dissection	3	2	1	0	-1	-2	-3
Virtual Car Project	3	2	1	0	-1	-2	-3

b. **I learned a lot.** Please circle the number that indicates the extent to which you agree with the statement "I learned a lot" for each project.

PROJECT	I Learned a Lot						
	agree						disagree
Bridge Project	3	2	1	0	-1	-2	-3
Engine Dissection	3	2	1	0	-1	-2	-3
Virtual Car Project	3	2	1	0	-1	-2	-3

c. **It was worth the time.** Please circle the number that indicates the extent to which you agree with the statement "It was worth the time" for each project.

PROJECT	It Was Worth the Time						
	agree						disagree
Bridge Project	3	2	1	0	-1	-2	-3
Engine Dissection	3	2	1	0	-1	-2	-3
Virtual Car Project	3	2	1	0	-1	-2	-3

d. **It helped me understand what engineers do.** Please circle the number that indicates the extent to which you agree with the statement "It helped me understand what engineers do".

PROJECT	It Helped Me Understand What Engineers Do						
	agree						disagree
Bridge Project	3	2	1	0	-1	-2	-3
Engine Dissection	3	2	1	0	-1	-2	-3
Virtual Car Project	3	2	1	0	-1	-2	-3

Please provide some comments about the projects (what did you like about it, what didn't you like, how can it be improved):

Bridge Project
Engine Dissection
Virtual Car Project

What was the best part of the course and why?

What did you like least about the course and why?

What are the major strengths and weaknesses of the instruction team?

How could the instruction team improve the way the class was run?

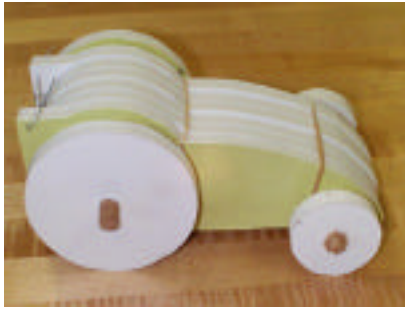
Appendix D: ABET Assessment Survey Form

Please indicate the extent to which this particular course contributed to your development of the following skills, where:

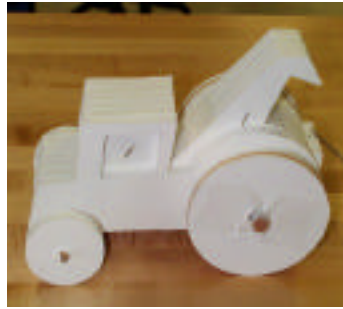
"A" is "very much",
 "D" is "some",
 and "G" is "not at all":

	a	b	c	d	e	f	g
an ability to apply knowledge of mathematics, science, and engineering							
an ability to design and conduct experiments, as well as to analyze and interpret data							
an ability to design a system, component, or process that meet desired needs							
an ability to function on multi-disciplinary teams							
an ability to identify, formulate, and solve engineering problems							
an understanding of professional and ethical responsibility							
an ability to communicate effectively							
the broad education necessary to understanding the impact of engineering solutions in a global and societal context							
a recognition of the need for, and an ability to engage in, life-long learning							
a knowledge of contemporary issues							
an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice							

Appendix E: Virtual Car Design Examples



Racer (Default)



Tow truck (Default)



Pickup (Default)



Wheelie (Default)



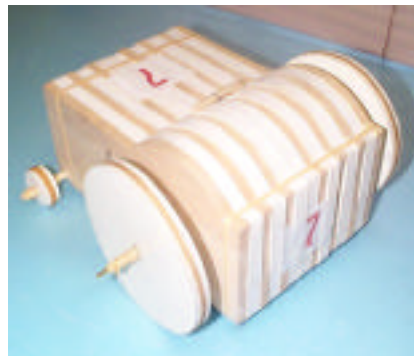
Puth's Car (Spring 2000)



Balsa Racer (Autumn 2000)



The Bug (Autumn 2000)



Crate (Winter 2001)



Pinky (Winter 2001)

Appendix F:
Informational Brochure for Virtual Car 2.0

(Attached)

Appendix G: Author Biography

Michael J. Safoutin is a PhD Candidate in the Mechanical Engineering Department at the University of Washington. His experience with courseware development began in 1984 when he authored several Apple-II based science learning modules as an undergraduate worker under an NSF grant. After receiving his Master of Science from the University of Illinois at Urbana-Champaign in 1990, he joined the director's office of the EPA National Vehicle and Fuel Emissions Laboratory and became involved with automotive vehicle modeling and policy issues in support of the Partnership for a New Generation of Vehicles (PNGV). At the University of Washington, he has continued his focus on engineering education by developing module catalogs for the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL); coordinating the design and operation of the Integrated Learning Factory design education facility for the Manufacturing Engineering Education Partnership (MEEP); serving on the staff of the Center for Engineering Learning and Teaching (CELT); and most recently taking on a lead instructorship for ENGR 100, Introduction to Engineering Design, where he developed the *Virtual Car* courseware. His research interests include engineering design theory and engineering education.