Customizable Simulation-based e-Learning Tools for STEM Education

The Massachusetts-based company ATeL, LLC, with the partial support from the National Science Foundation, Department of Labor and Department of Defense has developed highly interactive simulation-based online games and customizable virtual laboratories (vLabs) for STEM education. The vLabs are designed to spark students’ interest in learning science and technology and help them better understand technical concepts and fundamental principles and laws underlying natural processes and the operation of familiar devices and systems (e.g., home appliances, mobile phone, alternative energy sources, etc.), as well as to help students master certain performance based skills in an online environment. The vLabs can be used in conjunction with the related hands-on labs to form the hybrid laboratories. The virtual activities can be tailored to any educational level, from middle school to college, and can be combined with hands-on activities to form hybrid labs for blended learning.

Interactive activities can dramatically enhance students' online learning experience by transforming conventional passive “e-learning by reading and watching” into much more effective active “learning by doing”, “project-based learning”, “problem-based learning, and others.

To learn more visit the ATeL website at http://ATeLearning.com.
Classical Mechanics in the Context of Golf Game

The e-learning module “Golf: Virtual Educational Playground” enables students to study many topics of classical mechanics. The simulations can be run in either Putt or Chip shot modes. There are several underlying physical and mathematical models of various degree of sophistication employed to simulate strokes and ball motion. This makes the module appropriate for students of different educational levels – from middle school to university.

A simulation is task and learner neutral, i.e., it models a process, an object/system construction and operation, or a learning situation. Within simulation functionality, there are no restrictions on the user’s actions.

In contrast with a simulation, a virtual experiment is a guided activity which focuses on a particular task. In addition to a simulation, a virtual experiment includes specific learning objectives, scenario/assignment, worksheets, assessments, and, most importantly, step-by-step instructions for students. Virtual experiments may also include optional auxiliary simulations, prerequisites, excerpts from interactive lessons and technical manuals, quizzes, and online reference resources. The student is expected to follow a thorough set of step-by-step instructions to accomplish a particular educational assignment. Whereas the Virtual labs incorporates several virtual experiments that can share simulations and supplementary e-learning resources.
Screenshots present various stages of the simulation “Chip shot”. Using controls, students can vary the angle and magnitude of the initial ball velocity, air resistance and wind direction, to examine how these parameters affect the ball trajectory, the elevation and the distance traveled. Graphics and diagrams, which can be expanded into large panels, help students bridge game-like activities with traditional subjects of physics and math. The expanded trajectory panel (shown on the left) helps students to understand and explore the concepts of vector, trajectory, velocity components, etc. The student can select parameters to be dynamically presented in a graphical format. The expanded graphic panel is shown in the top right.

The option to instantly switch between the US and metric systems of units is provided.
Screenshots of a virtual experiment based on the Putt simulation. In contrast to a simulation, which is task and learner neutral and has no restrictions on the user actions, virtual experiments are guided activities that focus on particular tasks. In addition to a simulation (bottom right), virtual experiment includes specific learning objectives, scenario/assignment, worksheets, assessments (top left) and step-by-step instructions for students (shown underneath the simulation). The student is expected to follow the step-by-step instructions to accomplish the educational assignment.

Using available simulations, templates and an easy-to-use authoring tool, instructors with no programming or scripting experience are able to produce new appealing and pedagogically sound virtual experiments.
The educational module *Distillation in Historical Context* links art, science and inventions. It has been designed to spark an interest of middle and high school students in science by considering some chemical and physics topics in historical contexts involving Leonardo Da Vinci drawings and inventions. First section focuses on the original drawings of antic distillation devices called *alembics* made by the great Da Vinci. These drawings which bear the author’s notes are stored at the *Biblioteca Ambrosiana di Milano*. Students embark on their journey with a brief introduction to Da Vinci’s bio, art and inventions. It follows with Leonardo’s drawings and interactive 3D models based on those drawings.
For deeper investigation into the design and operation of Da Vinci’s devices for separating liquids by exploiting differences in their volatilities, students may switch between three modes - Drawing, Model, and Exploration. In Drawing mode, students can zoom in the picture to scrutinize drawings, and read Leonardo’s notes translated into English. In Model mode, students compare an original drawing with the corresponding 3D model, zoom and rotate the model, and view its cross-section. Exploration mode is designed to help students study, in detail, the distillation process as it took place in Da Vinci’s devices. Student can conduct distillation experiments using either Leonardo’s alembics or modern chemical glassware and thereby journey from medieval devices to contemporary laboratory and industrial-scale equipment.

Interface and page fragments for the first chapter presenting Da Vinci bio and drawings of alembics with detailed descriptions. Radio buttons (top right) enable students to toggle between Drawing, Model (shown above), and Exploration modes. Students choose from amongst these three versions of Leonardo’s alembic to investigate.
A set of virtual laboratories enables students to conduct experiments and collect virtual data. Students can explore such processes as evaporation, boiling, and condensation in various liquids or they can investigate distillation processes in various two-component systems.

The e-learning tool enables students to explore the evolution of Da Vinci’s design and learn what motivated him to improve it, one step at a time.

Middle and high school students are able to perform virtual distillation experiments analogous to those performed by Da Vinci’s primitive system. Discussion is provided of Da Vinci’s efforts to prevent heating and cooling processes from interfering with one another.

**Future Work**

The future development of the module will incorporate sections that will introduce students to fractional distillation, seawater desalination, and petroleum refinery. We also plan to include sections that show how fundamental principles of evaporation and condensation along with gas laws are applied to the design of modern refrigerators and air conditioners.
Virtual Laboratories on Energy and Energy Conservation

ATeL Energy module focuses on alternative energy and energy conservation topics

Screenshots of a solar powered house simulation. The first screen of the simulation (shown in the left) enables students to vary the geographical location of the house, seasons, time of day and weather conditions and to observe how these factors affect the system power output. The second screen (on the right) helps students to explore major components of the solar power system. The controls and meters allow them to collect and analyze such data as current power generated by solar panels, total electrical energy produced by the system throughout the day and monthly savings due to the solar power system. Virtual experimentation helps students develop their understanding of all the pros and cons of a solar photovoltaic system.

After introduction to the solar power system and technical and economical aspects of supplying electricity using such systems the students can use the set of simulations that model and visualize the basic processes occurring in semiconductors.

The simulations shown above enable students to study photovoltaic effect in semiconductors and explore how various radioactive loss mechanisms in a semiconductor depend on the composition of the material. Students are able to vary light intensity and applied voltage and to study how these parameters affect the current-voltage characteristic of a photovoltaic device. This helps students better understand fundamental laws underlying the operation of photovoltaic panels.
An example of a virtual experiment “Influence of Thermal Wall Insulation on Energy Expenses” on the Heat Conduction that is designed to study heat transfer and thermal conductivity of building materials. In this particular experiment, students should determine the impact of wall insulation materials on the cost of maintaining comfortable temperature in a house. Students are able to vary thickness of wall and insulation materials, inside and outside temperatures, select different materials and instantly see how these changes impact energy consumption and the monthly utility bill. An instructional panel beneath the simulation displays step-by-step instructions for the student. An Excel spreadsheet (or simple worksheet) can be opened from within the experiment. It can also be printed out to use in traditional “paper and pencil” mode. The spreadsheet helps students conduct the experiment, collect and handle data. From within the main simulation an auxiliary simulation (shown in the middle left) can be called up for additional exploration. Each virtual experiment includes an associated test (bottom right). An embedded lesson (top left) provides “just-in-time” learning opportunity. An optional Instructor Agent keeps track of student actions and provides feedback and instructions to the learner. The Agent’s programming can be modified by the instructor.

In these and most other simulations a student can toggle between the American (British) system of units and the Metric system (SI).
In an energy efficient house, LEDs replace inefficient incandescent lamps and less efficient fluorescent lamps. Screenshots illustrated in Figure 4 enable students to understand the design and operation of a Light Emitting Diode (LED).

Screenshots of the simulation about Light Emitting Diode (LED) depict the inner and outer construction of a LED and a cross section of a PN junction illustrating the recombination of electrons and holes in the depletion region leading to the spontaneous emission of radiation.
Screenshots of ATeL simulations and virtual labs on HVAC-R. The simulation ‘Refrigerator’ (top right), demonstrates the arrangement of the various components in a refrigeration system, their functions and interconnections. Three panels of the simulation link different presentations of the processes and enable students to logically comprehend the association between the real physical process, an abstract P-T diagram of the cycle, and the second law of thermodynamics. The learners can explore the cycle in great detail using auxiliary simulations and built-in interactive lessons (top left). The simulation ‘Liquid Thermal Relay’ (bottom left) enables students to explore the operation of a thermostat used in a refrigerator and to study thermal expansion of liquids. The virtual lab can be integrated with a hands-on training module (bottom right) to create a hybrid laboratory.
The collage above illustrates the concept of a multilayered laboratory for exploration of electrical and heating/cooling systems of a residential house (A) that utilizes renewable energy sources.

By using a 3D model of the house, users will be able to explore its major systems and home appliances and study their underlying fundamental principles. The set of simulations (B) enables users to investigate how house geographical location, orientation, seasons, and weather conditions affect the performance of solar heating and photovoltaic (PV) system. Virtual activities (C) and (E) help learners explore the operation of the electrical and heating/cooling systems. By using the simulations that model and visualize processes occurring in semiconductors (D) users will better understand fundamental principles underlying the design and operation PV panels.

The simulation, shown in the image (F), allows users to explore how various wall and insulation materials, the thickness of wall and insulation, inside and outside temperatures, and the efficiency of a heating or cooling system affect heat flow through the wall and, hence, energy expenses.

In addition, users will be able to select various system devices and home appliances from online collections and observe how such replacements will affect a performance of the relevant system, as well as monthly or annual utility bills.
Solar Power - Roof Solar Heating System

The simulation models a roof solar heating system and allows users to explore how efficiency of the system depends on geographical location, seasons, weather conditions and some other factors.

Users are able to choose from a list of geographical locations of major American and foreign cities or enter a latitude of a particular place, rotate the house, vary the angle of the solar panel, change date, time and weather conditions and immediately see how these changes influence the corresponding solar irradiation within a day or total solar energy absorbed by the collector during a year.

This simulation is integrated with another simulation that models house heating/cooling and hot water systems.
Solar Power – PV Electrical System

The simulation enables users to investigate how the transformation of solar energy into electricity depends on panel geographical location, direction, tilt angle, season, daytime, and weather conditions.

This simulation is integrated with another simulation that will model a house electrical system.

A user is able to switch between fixed tilt and sun tracking models.
House Electrical System

The House Electrical System (Overview) simulation introduces users to the Grid-Tied Solar Power System. The panel on the right will display Power generated and consumed, as well as an average power balance during a day, a week, a month, or a year. In addition, the panel will dynamically present information such as total monthly energy consumed by home systems and appliances, produced by the PV panel and imported from and sent to the grid as well as the total amount of the electrical bill and the amount saved due to the use of solar power.

The users are able to change the type of solar panel, panel areas, and color, as well as the number of panels and weather conditions.

The Grid-Tied Solar Power System diagram enables user to further explore major devices that are required to build the system. Users are able to vary the total power of house systems and appliances and observe how this affects the balance between produced and consumed power. An optional chart demonstrates variations in energy consumption during business days, weekends, and various seasons.
The House Electrical System (Specification) simulation allows users to select various types and models of devices that make up a Grid-Tied Solar Power System. Users are able to review device specification and read a detailed device description. Auxiliary simulations and other learning resources help users get familiar with operational principles of the device and learn underlying fundamental principles.

When any system device is replaced with a different model the corresponding changes are displayed in the appropriated fields of the right panel and affect all other interlinked simulations.

The similar option will be available for all other systems such as HVAC, Lighting, Walls and Insulation, Kitchen, and Recycling.

**Virtual Experiment Example**

In this virtual experiment learners have to calculate energy savings due to installation of various types of PV solar panels.
A user will be able to select and open any room in the house, e.g. Kitchen (a) and explore how various models of kitchen appliances (e.g. an oven) affect energy consumption and the utility bill. Built-in auxiliary simulations and virtual experiments developed by our previous projects will allow users to study the processes and fundamental laws underlying operation of the selected appliances.

Notations:

(a) House kitchen. The panel on the right will allow users to observe how changes in model and/or parameters of appliances affect energy consumption.

(b) A selection window enables users to choose various models of the selected appliance from a drop-down list and review their design and major parameters.

(c) Physical appearance of the selected model of a kitchen stove.

(d) An auxiliary simulation that allows users to explore the heating and boiling processes of various liquids and mixtures. By varying the stove power and burner size, size and materials of a kitchen pot, liquid amount, etc. users can study the relevant processes and learn how cooking parameters and kitchen utensils affect energy consumption.

(e) The auxiliary simulation “Pressure Cooker” helps users understand the benefits of preparing food under higher pressure and learn how boiling temperature depends on pressure.

(f) An auxiliary simulation that visualizes the processes occurring inside a pot and pressure cooker and enables users to explore in depth phenomena such as evaporation and condensation.

(g) Screenshot of a page of an online lesson that provides descriptions and explanations of the processes occurring while a liquid or a mixture is heating and boiling.

(h) Physical appearance of the selected model of a refrigerator.

(k) An auxiliary simulation that models the design and operation of a refrigeration system, operational cycle of a heat pump (top right) and the second law of thermodynamics (bottom right). The processes in all three panels are synchronized to help users build a general picture of a refrigeration (heat pump) operation and better understand underlying fundamental principles and laws. Users are able to vary the temperature inside and outside the refrigeration chamber and investigate how this affects the refrigerator efficiency.

(m) A worksheet that is used to keep track of the virtual experiment and collected data.

(n) The auxiliary simulation “Thermostat” helps users learn about the operation of the device that controls the temperature inside the refrigeration chamber.

(p) An embedded lesson that allows users to learn the thermodynamic processes that make up the heat pump cycle.
Users can adjust default electrical load by selecting various lighting (screenshot below), kitchen and home appliances (screenshot above) and other electrical devices and calculate their house's electrical load. This will help students and general public get a good overview of how electricity is used in their house. Utility consumers will learn where they are spending money on electricity and how their utility bill can be lowered.

**Hybrid Laboratories**

In order to facilitate blended learning, virtual labs can be integrated with hands-on labs. These hybrid laboratories increase the learning impact of hands-on and virtual experimentation.

The combination of actual hands-on experimentation with realistic visualization and interactive simulation-based online exploration provide a thorough basis for the understanding of the scientific and engineering concepts underlying experimental techniques and studied processes and phenomena.
Adaptable Simulation-based e-Learning Module on Automotive Technology

The integrated Automotive Technology module is being designed to help students study the construction and functionality of the major systems and components of diesels, internal combustion engines and turbines, as well as to better understand underlying technical concepts and fundamental principles.

This standard (SCORM®) compliant open-ended online educational environment comprises simulations, interactive lessons, guided virtual activities, assessment, etc. The combination in one system of a variety of tools and resources for mastering practical skills, acquiring technical knowledge and learning fundamental principles enables instructors to seamlessly link training and learning into a single educational process that fosters a student’s deep understanding of basic principles and cause-and-effect relationships in engine design and operation. This will help equip students with transferable knowledge and skills that can be applied at their workplace.
The set of simulations “Engine block: Parts and Operation” (the first layer) enables students to learn engine parts and investigate an operation cycle. It can be run either in Parts or in Operation modes. The engine operation (on the left) is linked and synchronized with a Cam Timing Diagram (in the middle) and the chart displaying the Otto cycle (on the right). The student is able to switch the simulation in a Step-by-Step exploration mode to observe the connections between events taking place in the cylinder and parameter changes at any stage of the cycle. This helps students better appreciate Otto cycle by visualizing how thermodynamic processes occur in an engine.

The student can also click the “Part’s details” button and open part specifications including graphs and tables (top right).

The simulation shown in the second layer of the figure (bottom right) has been developed for the exploration of internal combustion engine ignition. By changing the fuel type and spark advance angle, students can investigate the impact of these parameters on engine performance and efficiency, as well as the dynamic of fuel burning at each step of the cycle.
The «Thermodynamics cycles» simulations allow the student to explore the Carnot (top left), Otto and Diesel cycles in details and compare them with each others (bottom right). From within the Carnot cycle simulation, auxiliary simulations (bottom left) that demonstrate the adiabatic and isothermal processes can be called. By varying such process parameters as temperatures, pressure, compression ratio, injected heat, etc. the student can gain deep comprehension of the differences of processes, their benefits and limitations.
The screenshots of the virtual laboratory “Influence of Compression Ratio on Engine Operation Cycle”. Following the detailed step-by-step instruction (shown underneath of the simulation), students have to vary the Compression Ratio (by changing the volume of the combustion camber) and Throttle Opening and explore how these changes affect engine cycle and performance. Digital and analog gauges display the major process parameters: fuel efficiency, torque, power, rotation speed, pressure, oil and water temperatures and oil pressure). This enables the learner to collect virtual data. Presentation of a realistically looking process operation, gauges and abstract process diagrams in a single window helps him/her to actually watch and understand how and why process parameters are related to an instant/current process status and how changes in engine design affect the shape of the Otto cycle chart and cycle efficiency.

The screenshot at the top shows the objectives of the lab. The screenshot at the bottom left presents an example of the built-in control quizzes where the student using drag-and-drop option should match the cycle processes with their names and descriptions.
The figure illustrates implementation of “Russian-doll” content structure by the example of the Fuel system. By triggering the simulation in the Parts mode (bottom left), students can explore major fuel system parts, zoom-in each of them, and read the part description. In the example, a fuel pump is selected. Then, the student can click the “Part’s details” button and open part specifications including graphs and tables. A lesson that presents relevant theoretical principles can be called up too. A page of rotary pump theory is shown in the top right screenshot. Two virtual mini-experiments are incorporated into this lesson. One experiment helps students explore the serial connection of the pumps (shown in the bottom right); in the second one – students deal with parallel connection. Such embedded experiments enhance student engagement and make learning scientific and engineering principles less dry and boring.

Many technical and engineering students, especially two-year college students, are more concrete than abstract thinkers. For such students, realistic images, animations and interactive simulations, embedded into online lessons, provide necessary assistance to better understand complex subjects and grasp engineering and scientific concepts.

In the online course “Turbines, Diesels and Internal Combustion Engines” science or engineering subjects are delivered in sets of modular lesson clusters. Each cluster comprises several short units of learning. Such architecture makes the course compatible with short bursts of on-line learning.

Examples of interactive lesson pages are presented in Figures 5 and 6. Each lesson page comprises a text narrative, colorful graphics and/or animations. Embedded animations are synchronized to the narrative and dynamically illustrate the topic content. Students, who prefer audio instructions, can listen to an expended lesson text read by a narrator.
A screenshot of a lesson page with a built-in virtual experiment which gives students hands-on experience with such difficult topic as vector diagrams of velocities and their applications in engineering. A realistic animated image of a turbine in the upper left corner helps a learner better envisage and associate the schematic representation with an actual original device. Following the step-by-step instructions displayed underneath of the simulation, the learner changes such system parameters as input steam velocity and blade rotation speed and observes the impact of those changes on the velocity diagram and turbine efficiency. After switching the simulation into the detail mode, the learner is able to collect and compare the numeric values of the system parameters.

The list of course chapters includes

- Steam Thermodynamics
- Propulsion Plant Equipment
- Pump Theory
- Diesel Engine Theory and Virtual Laboratories
Screenshots of lesson pages and built-in interactive simulations that illustrate our approach to design multimedia course and integrating different resources.

The top left screenshot in Figure 9 shows a page of an interactive lesson on Rankine cycle heat engine. It illustrates how the subject is approached from the different points. The animated diagram of a heat engine on the left shows what is going on in each part of the engine. The classical temperature vs. entropy diagram on the right enables students to learn the theory of the specific cycle implemented in a steam power plant. The link between visualized processes in the engine parts and the scientific diagram brings the subject within the grasp of learners who lack abstract thinking skills. Text and audio explanations are synchronized with the status of visual objects.

The screenshot in the top right illustrates the page containing a realistic animation of a two-stroke diesel engine whose operation is synchronized with Diesel cycle diagram on the right.

The simulation shown in the bottom left helps students understand processes and potential problems associated with a pipeline expansion due to increasing its temperature. For instance, a breakdown of expansion bearings can cause cracks or may even rupture the pipeline. The relations between mechanical strains in the pipes and temperatures are presented in the graphs.

The realistic animation in the bottom right shows basic turbine design.
Screenshots of the virtual laboratory for testing a Fairbanks-Morse opposed piston diesel engine in a dynamometer test cell. The core components of the lab are highly interactive simulations that imitate the testing processes for diesel engines. The lab facilitates three type tests: idle test, load test, and generator mode test (constant speed).

The screenshot in the bottom right displays a two-stroke FMOPDE being mounted onto the dynamometer in a virtual test cell. The simulation enables students to perform virtual measurements of engine rotation speed, horsepower, torque, fuel consumption, and other critical parameters of engine operation. Fuel temperature, air temperature and pressure in the inlet manifold and the ambient air temperature and pressure are monitored as well.

As in an actual Dynamometer Test Cell, students are able to vary the throttle position and dynamometer load setting. By these means they can collect virtual data, as well as browse, save and export the data (bottom left) to any standard data-handling software including Microsoft® EXCEL. Various dependencies between parameters can be selected and presented into two graphical panels. The virtual lab includes an associated test (top right). The trainee is able to answer the questions either online, or print out a hard copy and use the traditional “paper and pencil” method. An interactive lesson is incorporated in the lab (top left) for “just-in-time” learning.
ATeL has designed an innovative Intelligent Online Tool for Hands-on Skills Training and Performance-based Assessment (patent pending) that addresses the needs of today’s online technical training and academic distance learning in engineering and technology programs and acts as a supplement or sometimes as a substitute for conventional workplace related hands-on practice and engineering/technology laboratory exercises.

This simulation-based tool enable learners to practice realistic workplace tasks and lab assignments online. The application can be run in three modes – demo, practice, and assessment. It direct learners through all of the procedures required for completing the assignment, forcing them to use right techniques, instruments, specific devices, etc. It also controls learners’ actions and provides remediation tips and feedback. In the assessment mode, the program can be used for skills and knowledge evaluation and performance prediction. The tool employs highly sophisticated Artificial Intelligent (AI) Engine that can handle complex tasks and branched workflows. The performance-based assessment provides a reliable way for the evaluation of personnel preparedness, skill decay, and performance prediction.

The supplementary authoring toolkit enables instructors with no programming or scripting experience to build new virtual learning, training and assessment assignments.
ATEL e-learning portals embrace a simple proprietary learning management system (LMS) that helps instructors manage learning content, split students into groups, create assignments for student groups, and keep track of students’ performance. Each assignment may include one or several simulations and/or virtual experiments, teacher notes for the assignment and additional notes for each resource. The assignment can be associated with one or several student groups. This allows instructors to tailor tasks to student backgrounds and specific educational goals and course content.

The LMS can be integrated with major open source or commercial LMS implemented in schools and colleges.
The ATeL authoring tool enables instructors, who do not have programming or scripting skills, to create and alter virtual experiments. Using templates and pre-existing simulations an author can create efficient online activities.

The screenshot to the right is of a template for creating step-by-step instructions. It provides the look and feel of a typical MS Word template.

The screenshots to the left is of the interface and template for creating step-by-step instructions. The list of question types to choose from includes:

- multiple choice,
- multiple selection,
- reordering,
- open response,
- estimate

New virtual experiments can be instantly published on a public or secure website and become accessible through a learning/content management system.

The authoring tools are fully portable and can be used on Windows, Linux and Mac platforms with all major Internet browsers.

Activities created using the tools are fully compliant with SCORM and other emerging e-learning standards and can be run under any standard conformant learning management system (LMS) and learning content management system (LCMS).
An example of the student view of the assign page. Student access can be limited to only current and previous assignments, corresponding instructor’s tips and notes and supplementary resources.
Science Pilot Project: Exploring Simulation and Virtual Experiment Tools for Science Education at the University of the Western Cape (South Africa)

Submitted and compiled on behalf of the eLearning Development & Support Unit by the eLearning Development & Support Unit Research Team

Date: 1 March 2010

EXECUTIVE SUMMARY

The Science Pilot Project and its evaluation aims to inform the potential of adopting eLearning simulation and virtual experiment based tools specifically, for Science learners at UWC. A summative evaluation was carried out. Summative evaluations are carried out in the post completion stage of the project, these evaluations are undertaken to assess either the advancement towards the attainment of project goals, if these goals can be attained, or the overall outcomes of the project. Evaluation at this stage is the process of assessing the value of a project at the conclusion of its actions (Cloete et al 2006:250 – 253).

The learners were handed and completed a questionnaire at the end of the project. The questionnaire was guided by and covered the following elements: Accessibility through UWC LMS; value added on comprehension of topic; user-friendliness and levels of self-directed use. Each simulation eTool was separately rated by the learners: ATeL; Active Physics; PhET; VPython

RESULTS

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<th>Virtual Experiment Tool</th>
<th>Value added on subject/topic comprehension</th>
<th>User-friendliness</th>
<th>Levels of self-directed use</th>
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