Yakov Cherner, ATeL, LLC

Dr. Yakov E. Cherner, a Founder and President of ATEL, LLC, combines 20+ years of research and teaching practice with extensive experience in writing curricula and developing educational software. He is the author of an innovative concept of multi-layered simulation-based conceptual teaching of science and technology. This instructional approach uses real-world objects, processes and learning situations that are familiar to students as the context for virtual science and technology investigations. To facilitate this methodology for corporate and military training, and academic education, his company developed a new ground-breaking e-learning solutions and relevant authoring tools. Yakov holds an M.S. in Experimental Physics, and Ph.D. in Physics and Materials Science. He has published over 60 papers in national and international journals and made dozens presentations at various national and international conferences and workshops. Dr. Cherner is a Principal Investigator of several government funded educational projects.

Arnold Lotring, Submarine Learning Center

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Innovative Simulation-based Online System for Learning Engineering and Training Sailors’ Technical Skills

Abstract

This paper describes the simulation-based online training course “Applied Engineering Principles”, that is being developed to assist submarine technical personnel in understanding applied engineering principles as well as to enhance their skills in preventing and troubleshooting emergency situations. The system combines educational and training capabilities.

The system challenges the learner to explore the design and operation of several major devices and their components in a virtual computerized environment. The underlying technological principles and scientific laws are linked to the virtual reality experience. The system is designed with a flexible multi-layered and open-ended architecture. It comprises virtual experiments, interactive lessons, problem exercises, quizzes, integrated assessment and auxiliary tools for instructional modification. All training resources are based on a uniform pedagogical approach and are conceptually linked in such a way that they compliment each other. The system employs “learning-by-doing” and problem-based training methodologies that prove to be effective for all learners including those with limited technical training but who will be assigned to highly technical job areas. This new approach attempts to provide alternate opportunities for the learner to understand and master technical training topics.

The interactive simulation-based course “Applied Engineering Principles”, can work well in many settings both outside and inside the classroom, over the Web, Intranet or on a stand-alone computer. The simulations can be utilized as capstone experiences to a classroom lecture series as well.

This paper focuses on the chapter Steam Power Plant of the ”Applied Engineering Principles” curriculum.

The vast majority of simulation-based learning systems currently used for military training purposes focus primary on new personnel familiarization and the development of specific practical procedures and maintenance skills. In contrast, most e-learning solutions for teaching technical disciplines implemented in academic institutions are designed to provide fundamental knowledge in a particular area.

The simulation-based engineering training system, ENGSKILLSNET, currently being developed by the Submarine Learning Center (SLC) is designed to achieve dual objectives: to enhance sailors’ skills in maintenance, troubleshooting and recovering from casualty (or infrequent) operations and to assist submarine technical personnel in learning applied engineering principles. This approach combines exacting simulations of actual operating systems along with opportunities for the student to master complex engineering principles through the association of real life observations of their acquired experiences and understanding. Because of that, the system comprises two major parts: (1) modules that simulate the operation of the major submarine systems and devices (ENGSKILLSNET),...
and (2) modules that help visualize what are the underlying principles for these systems and devices
(Applied Engineering Principles).

The Applied Engineering Principles curriculum design adapts and integrates cognitive information processing, systems analysis, and adult learning theories. It employs effective “learning-by-doing” and problem-based training methodologies. The system has a flexible multi-layered and open-ended architecture. All training resources are based on a uniform pedagogical approach and conceptually linked in such a way that they complement each other and enable students to tackle the learning subject from several directions. The system challenges the learner to virtually explore the design and operation of major devices and their components and links this experience with underlying technological principles and scientific laws. By this means the system bridges technical training and science/engineering education.

Figure 1. Steam Power Plant Simulator (in the center) enables a student to modify system parameters by changing valve status. The gageboard displays the current values of basic parameters. From within the simulator the student can call associated simulations and interactive lessons for “just-in-time” exploration of underlying science and engineering principles and concepts.

The Steam Power Plant Simulator, which enables a sailor to simulate operations in the steam power plant, is linked with interactive lessons of the online curriculum “Applied Engineering Principles” (Fig. 1). The e-learning courseware has been developed by the Massachusetts-based company ATeL, LLC. The simulations embedded into the lessons visualize and illustrate an internal design and basic operation of power plant components. Many sailors (or sailors to be), to whom our training courses are addressed, lack science and engineering backgrounds. Realistic
visualizations motivate students and help them better grasp the engineering and scientific concepts and understand equipment design and operations.

State-of-the-art graphical interfaces and sophisticated models provide an "inside" view of the process and allow students to replicate tasks that are conducted in the workplace. Sailors can quickly and safely experiment with a variety of scenarios and instantly see the effects of their experimentation, become familiar with the internal structure and operation of complex devices and systems, and learn effective sequential processes, along with the development of a variety of appropriate professional skills. Highly interactive simulations enable students to make choices that lead them down different paths toward different outcomes. Students might have some intuitive sense of what went right and wrong during the exercise, but clear system feedback allows the experience to become tangible to the learner’s experience. The learners’ individual choices determine where they find themselves later in the simulation. So, the students make mistakes and learn directly from their own mistakes and the outcomes of their own actions. This approach makes the students more open for internalizing the acquired knowledge and skills.

A training cycle begins with the virtual exploration of a particular process or system using the simulator. Then, the trainee is then provided with an interactive lesson that focuses on underlying technological and scientific principles to support the learner’s conceptual understanding. Figure 2 illustrates how the simulations present to a student the design and operational principle of a steam turbine.

![Figure 2](image.png)

**Figure 2.** The simulations demonstrate turbine design and basic operational principles.

Realistic Java or Flash simulations immerse trainees in job related virtual environments enabling them to (1) observe the physical processes insightfully at different levels of detail, (2) analyze constraints between relevant parameters, (3) push these parameters beyond normal allowed values to simulate infrequent operating conditions or casualty situations, (4) run “what if” scenarios, and (5) acquire data...
from virtual experiments for detailed analysis and comparison to actual operating conditions in a theory to practice approach. Such complex activities help trainees master troubleshooting skills and better appreciate the potential causes of hazardous or even emergency situations.

The *Applied Engineering Principles* (AEP) curriculum uses processes and objects that are relevant to submarine equipment and environments which are familiar to sailors from their real life experience as the context for science and technology investigations. Such an approach has shown to be effective for adult learners. It bridges the gap between the abstract and tangible aspects of particular scientific/technical principles and their real-world applications. This helps students who are practical thinkers grasp the relationship between science and math abstractions and observable facts and phenomena. Applied Engineering Principles software uses the techniques and pedagogy developed by ATeL, LLC with partial support from the National Science Foundation.

Figure 3. Virtual experiment above exemplifies a typical activity built into an interactive lesson.

Along with a quantity of simulations the courseware embraces a number of virtual experiments. A virtual experiment comprises a simulation, as well as a specific assignment and thorough step-by-step instruction for the student how to accomplish the assignment. Virtual experiments engage students in online learning while helping them retain and apply what they have learned. Figure 3 presents the virtual experiment that is offers to students after they learned basic design and operation of a steam turbine. It is designed to give students hands-on experience with such
A difficult topic as “Vector velocity diagram”. 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 in the bottom panel, the learner changes such system parameters as input steam velocity and blade rotation speed. The student can observe 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.

One of the main goals of submarine engineering training is to help sailors to understand equipment limitations and what conditions may lead to damage or reduced operating capability. Safe submarine operation requires the highest level of engineering reliability. Such reliability can only be assured by providing adequate engineering systems design and training operators to properly operate these systems. To achieve these objectives the submarine engineer necessarily has to comprehend the associated physical processes and causes responsible for changing particular operational parameters. Interactive simulations facilitate the evaluation of operational sensitivities and understanding the causes of certain parameter restraints. It is very effective to ask the student to make the predictions and use the simulations to provide them with instant results in a visual and easy to appreciate format.

Here is an example how Steam Power Plant Simulator can work together with AEP simulations to enhance sailors understanding. Manipulating the virtual valves at the simulator the sailor is able to alter a mass-flow rate through a nozzle to turbine. This results the change in the turbine power output. The simulations presented in Fig. 4 demonstrate how this change affects the turbine performance. The trainee will see that increasing turbine power and therefore the rotation speed beyond a certain limit may result in turbine damage and even distortion.

![Figure 4](image_url)

The left simulation demonstrates how changes steam pressure at the nozzle inlet affect the steam pressure and velocity when it approaches turbine blades. The right simulation shows the correlations between the turbine power and rotation speed, as well as the processes that occur when the speed exceeds the critical limit and the turbine rotor begins to be destroyed. This simulation is designed to help a trainee to understand that although the greatest power of a steam turbine can be received at the greatest possible rotating speed of its shaft, there are some limits due to the colossal centripetal force tending to pull out a blade from the disk.
The Figures 5 - 7 illustrate how interactive simulations incorporated into the learning system help trainees better understand fundamental physical principles at a very basic conceptual level appropriate for learners with average or limited technical backgrounds in physics and math. Most simulations and animations, which are parts of the described course, can also be used independently for various training subjects.

Figure 5. The fragment of a steam plant system during the warm-up stage is shown above. Using this simulation the learner is able to explore all processes occurring at that stage. Particularly, he/she can see what is going on inside the turbine (b) and condenser (c).

Figure 6. The top right simulation helps a learner to understand processes and potential problems associated with a pipeline expansion due to increasing its temperature. For instance, a breakdown of expansion bearings can cause the cracks or even rupture of the pipeline. The relations between mechanical strains in the pipes and temperatures are presented in the graphs.

Figure 7. A converging-diverging nozzle (or De-Laval nozzle) is presented at the top of the picture. Steam pressure and steam velocity dynamically measured along the horizontal axis of the nozzle are shown in the graph (bottom left) and the diagram (bottom right). The simulation assists learners in comprehending the relationships between external pressure and processes occurring inside the nozzle and when steam exits it. An understanding of these processes including turbulence, which substantially affects turbine performance, is crucial knowledge factor for submarine engineering personnel to master.

In the Applied Engineering Principles course science or engineering subjects are delivered in sets of modular lesson clusters. Each cluster comprises several short units of learning called interactive lessons. Such architecture makes the course compatible with short bursts of on-line learning. An example of an interactive lesson page is presented in the Figure 8. 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.

Figure 8. An example of an interface of an interactive lesson that is dedicated to the topic 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 the learners to study the theory of the specific cycle implemented in a typical 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 synchronized with the diagram help the learner to successfully follow the lesson content.

Along with simulations and animations most lessons include quizzes of various types, control questions and virtual experiments. Each virtual experiment includes one or more of several connected simulations and a step-by-step instruction sequence to assist students in learning how to accomplish a specific assignment.

Some assignments incorporated in the Applied Engineering Principles lessons require students to make certain calculations that involve knowledge and skills acquired in the previous course chapters. Since an onsite instructor may not be available to help students in completing these tasks, the system includes a smart component called the problem solving tutor/assistant (PST).

When a PST is built into a lesson, it offers students the task and provides all necessary tables, reference data, and its engineering calculator. If the learner has a problem in getting a final
answer or gives an incorrect answer, the PST rolls one step back and offers to help perform interim auxiliary calculations. If the learners still has a problem the PST provides a template of the formula that has to be used. If all of that does not help, PST opens or points to the lesson topic that must to be learned before completing the assignment.

An example of the PST is shown in the Figure 9.

![Figure 9](image)

**Figure 9.** The Problem Solving Tutor helps the student to calculate a Rankine cycle turbine efficiency. The problem is presented in a format that is easily associated with a submarine engine and T-s diagram studied earlier. The problem description is displayed in the bottom left panel. If the student fails to complete several calculations correctly, the PST displays the formula template (bottom right) and recommends using numerical data from the built-in a steam table.

References:

