AC 2008-2205: SIMULATION-BASED LEARNING OF DISTILLATION PRINCIPLES IN HISTORICAL CONTEXT: FROM DA VINCI'S ALEMBICS TO MODERN APPLICATIONS

Yakov Cherner, ATeL, LLC

Yakov E. Cherner, Ph.D. a Founder and President of ATEL, LLC, taught science, engineering and technology disciplines to high school, college and university students. He has extensive experience in writing curricula and developing educational software and efficient instructional strategies. Dr. Cherner introduced 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, engineering and technology investigations. He also proposed and implemented the pioneering concept of integrated adjustable virtual laboratories. To facilitate these methodologies for academic education, corporate and military training, his company developed new ground-breaking e-learning solutions, as well as relevant assessment and authoring tools. Dr. Cherner holds an MS in Experimental Physics, and Ph.D. in Physics and Materials Science. He published over 70 papers in national and international journals and made dozens presentations at various national and international conferences and workshops. Dr. Cherner has served as a Principal Investigator for several government-funded educational projects.

Jerry Meldon, Tufts University

Jerry H. Meldon, Ph.D. received a BE in Chemical Engineering from the Cooper Union in 1968 and a PhD in Chemical Engineering from MIT in 1973. Since 1977 he has been on the faculty of the Chemical Engineering Department at Tufts University. His primary research interests have been mass transfer with chemical reaction, separation processes (especially membrane processes) and mathematical modeling. For nearly 20 years beginning he was a consultant to the Exxon Corporate Research Laboratory in Annandale, NJ. His abiding interests in inorganic membranes for gas separations, and coupled reaction and separation, grew out of his employment there while on leave in 1987. He has received two US patents for separation processes whose conception evolved from projects in which he developed mathematical models of simultaneous mass transfer and chemical reaction.

Anatoly Peresunko, Southern Federal University (Russia)

Associate Dean and Professor of Chemistry, Southern Federal University (Russia) Research interests include investigation of properties, crystal structure and phase transitions of solid-state inorganic compounds and materials; chemical education.

Simulation-Based Learning of Distillation Principles in Historical Context: From Da Vinci's Alembics to Modern Applications

Yakov E. Cherner*, Jerry H. Meldon, Anatoly F. Peresunko*****

***ATeL, LLC, ** Tufts University, *** Southern Federal University (Russia)**

Introduction

One of the most difficult concepts in physical chemistry for grasp – and, because of its wide range of practical applications, one of the most important concepts - is that of *relative volatility*. Although grade-school students are familiar with the related concept of *boiling*, most require formal instruction to be able to distinguish it from *evaporation*. The concept of *vapor pressure* is taught in college-level general and physical chemistry, and thermodynamics, but is not well retained.

Chemical engineering professors quickly realize the necessity of emphasizing, repeatedly, that when *multi*-component solutions *begin* to evaporate, the emerging vapors consist *not* only of the most volatile component, but in fact contain *all* of them, albeit in different proportions than those in which they prevailed in the liquid. This concept is crucial to understanding the physico-chemical mechanisms exploited in air conditioning (as well as cooling via sweating and evaporation), refrigeration, power plant steam cycles, distillation of alcoholic beverages and petroleum fractions, and numerous other important processes.

Da Vinci's Alembics

One way to spark student interest in such abstract subjects is to consider them in earlier historical contexts involving famous persons. Undoubtedly, Leonardo Da Vinci was and remains one of the most outstanding, mysterious and fascinating personalities of all time. This paper describes a simulation-based e-learning module designed to motivate and maintain student interest in studying distillation and related phenomena, and their practical applications, in historical perspective. Using interface controls, the student can select among sets of laboratory equipments and thereby journey from medieval alembics to contemporary laboratory and industrial-scale equipment.

The first section focuses on the early work of the great Da Vinci. 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.

Da Vinci took it upon himself to develop and perfect a practical means to separate liquids by exploiting differences in their volatilities (i.e., their boiling points or, equivalently, their vapor pressures). He called the fruit of his labor the "alembic." His original drawings and a description of his efforts motivate students to explore the physicochemical basis for his invention. The Da Vinci collection at the Biblioteca Ambrosiana *di Milano* includes three drawings of alembics with author's notes.

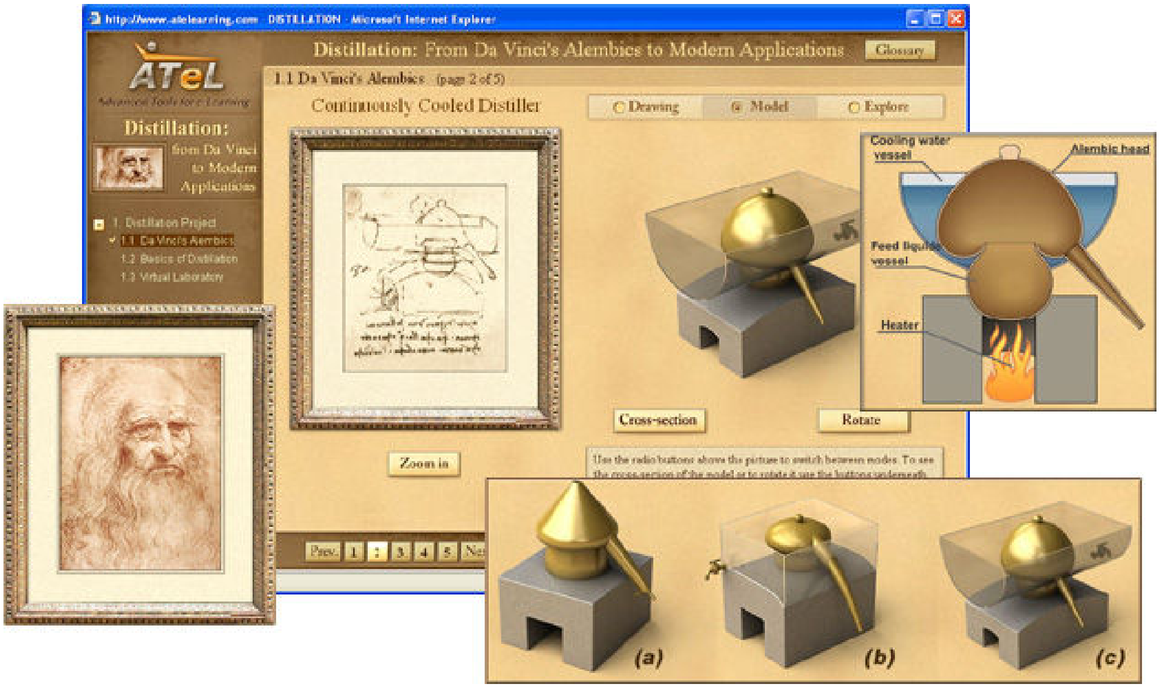

Figure 1. Interface and page fragments for the first chapter presenting Da Vinci bio and drawings of alembics with detailed descriptions. Radio buttons (top right) enable ~~a~~ students to toggle between Drawing, Model (above) and Exploration modes. Students choose from amongst three versions of Leonardo's alembic to investigate.

Our e-learning module 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.

For deeper investigation into the design and operation of Da Vinci's prototypes, students may switch between three modes - Drawing, Model, and Exploration. In Drawing mode, ~~the~~ student can zoom in to scrutinize drawings, and read descriptions and Leonardo's notes. In Model mode (Fig. 1), 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 early design. Single-component mixtures are continuously heated at constant pressure; and the emerging vapor is continuously condensed and collected.

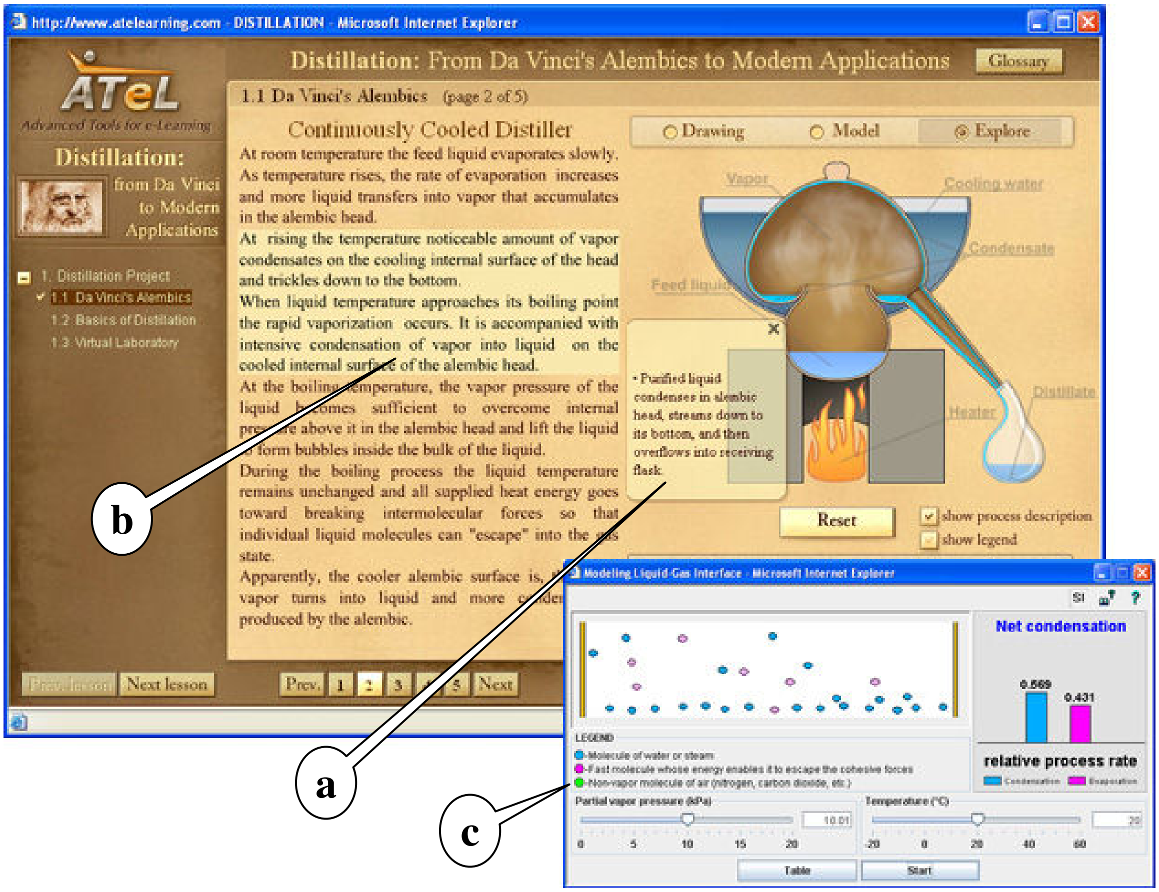

Figure 2. Exploration mode allows students to study processes occurring inside Da Vinci's early prototype. A pop-up panel (a) and a narrative (b) describe the instantaneous status of the process. From within this animation students are able to launch simulation and explore the processes of evaporation and condensation in detail.

<u>Virtual Laboratories</u>

The described e-learning module provides students with "just-in-time" learning opportunities. Embedded interactive lessons (Fig. 3) enable students to explore such the principles of evaporation, condensation, phase transitions, phase equilibria, and intermolecular forces. Simulations and virtual experiments (VE's), which may also be launched from lesson pages, help students develop deeper understanding, maintain interest, and make the learning process more interactive and engaging.

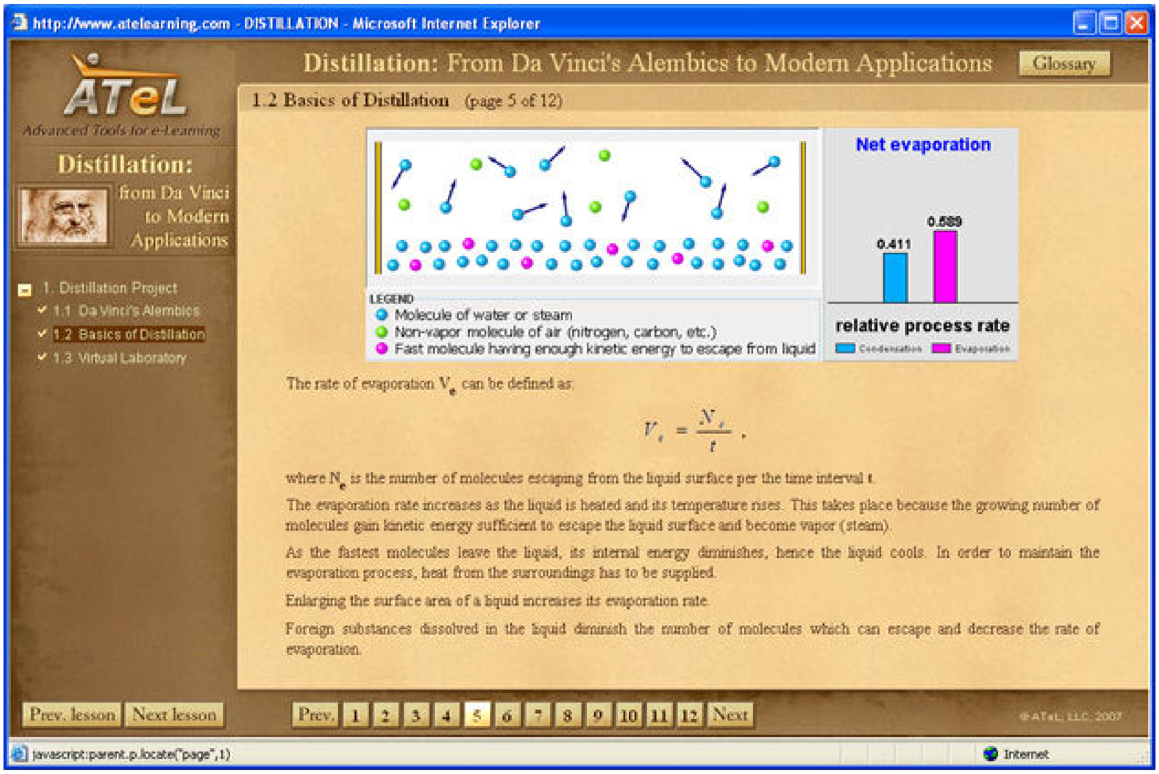

Figure 3. An example of a typical page of an embedded lesson. By clicking on the image a student can launch the corresponding simulation or virtual experiment and explore the process hands-on.

Each VE focuses on a particular task, includes learning objectives, prerequisites, main and auxiliary simulations, assignments, step-by-step instructions, embedded assessment, excerpts from interactive lessons, and help.

The first virtual laboratory shown in Fig. 4, in which students may experiment with single-component liquids such as water, ethanol, acetone, glycerine and oil, helps them learn that boiling points, heat capacity, heat of vaporization, *relative volatility*, and other parameters depend on intermolecular interactions and, therefore, liquid composition.. Simulations give students menus of labware including Da Vinci's alembics, traditional chemical glassware and two types of commercial distillers. By comparing processes in a variety of distillation devices, students can evaluate the advantages and disadvantages of each.

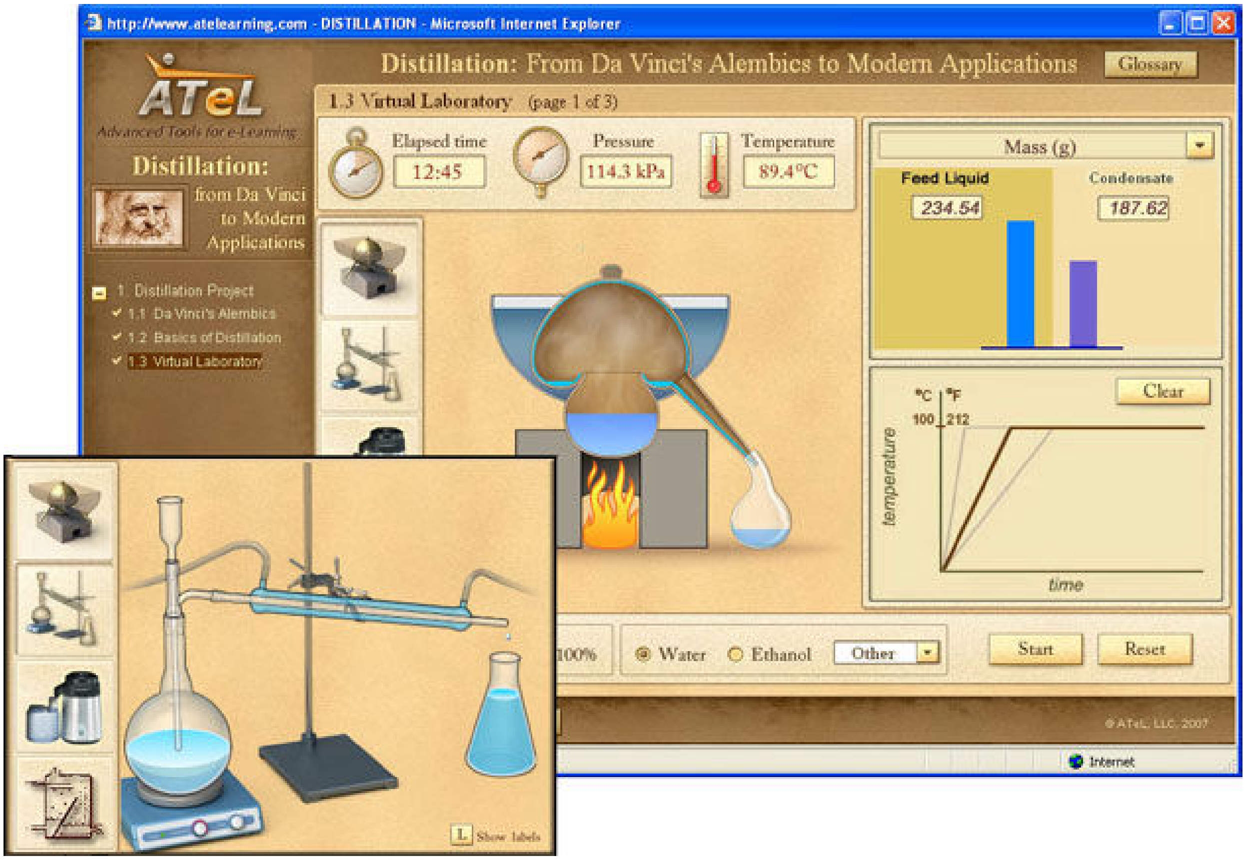

Figure 4. A set of virtual laboratories enables students to conduct experiments and collect virtual data. Students can choose a liquid from a list. Using the tool bar on the left they can select labware. They can also able to vary the heating rate and observe the dynamics of the processes.

One module includes virtual laboratories that explore two-component systems. They enable students to conduct a wide variety of experiments. Using interface controls students can select a system to explore, set concentrations, and adjust pressure.

As a distillation experiment proceeds, students observe continuously changing compositions of the residual liquid, emerging vapor and the condensate; plus temperature (Fig. 5). They are motivated to explore why temperature does not remain constant, and thereby grasp the concept of *vapor pressure* and the notion that different chemical species have different vapor pressures that increase at different rates with temperature.

Student understanding of *vapor pressure* allows the instructor to introduce the more advanced concept of *dynamic equilibrium* between liquid and vapor phases, and its shift with temperature.

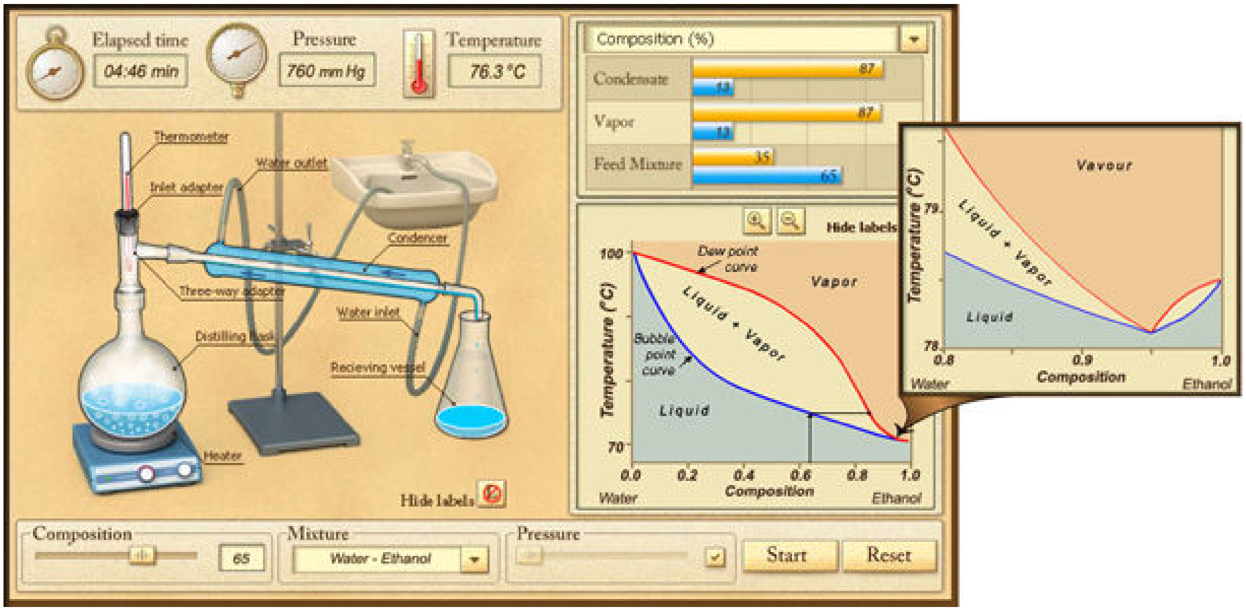

Figure 5. Virtual laboratory designed to investigate distillation processes in two-component systems. Using interface controls students can select a system and set its initial composition and pressure. Charts and diagrams present instantaneous system parameters. A zoom-in option enables students to enlarge areas of particular interest. A close-up of the azeotropic distillation box is shown at right.

Once these concepts have been taught, students are equipped with the capacity to *invent* applications that exploit differences in volatility or, at the very least, to appreciate the basis for air conditioning and refrigeration, and distillation to produce alcoholic beverages and gasoline.

A supplementary easy-to-use authoring tool enables instructors with no-programming experience to modify pre-existing and create new interactive virtual activities suitable for various educational levels from middle school to universities, and adjust them according to curricula and learning objectives.

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 condensations along with gas laws are applied to the design of modern refrigerators and air conditioners.

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