Interactive Simulation-Based e-Learning Tools for Engineering Education

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Simulation-based e-learning is rapidly becoming a significant part of most educational processes as an important component of the next generation of e-learning materials [1-4]. As higher communication bandwidth becomes more accessible, it becomes an effective counterpart of the learning process.

The highly interactive integrative learning system 'Active Learning Suite' (*ALSuite*) is the next step in simulation-based e-learning for STEM education and corporate training. It uses real-life situations and objects, such as those related to the home, automobiles, sports, and telecommunications as the context for science and technology investigations. *ALSuite* is based on a proven pedagogical assumption that students better learn and master science and technical concepts if they have experience with the concrete phenomena that are being studied and if they are aware of the potential applications of the knowledge they are acquiring.

The realistic ALSuite simulations immerse students in workplace-like virtual environments. State-of-the-art graphical interfaces and realistic models provide an "insight" view of the process and allow students to imitate authentic tasks that are similar to or identical with those tasks they are required (or will require) to do in their workplace. Students can speedily and safely experiment with a variety of scenarios and see the effects of their experimentation, become familiar with internal structure and operation of complex devices, and learn effective sequential processes, along with the development of other vocationally appropriate skills.

ALSuite framework includes Simulations, Virtual Experiments, Interactive Lessons, Problem Solving Tutor, scriptable and animated Instructor's Assistant, ancillary tools, and more.

ALSuite's active framework provides the capability of accommodating a variety of educational resources available in electronic format, including Web resources, and furnishes a live linkage across multiple representations. Recent educational research suggested that such dynamic linking is an important feature in many effective educational software designs. The framework enables diverse components to co-exist while sharing resources on a computer.

Simulations, virtual experiments, dynamic graphs, tables, streaming video, students' notebooks, journals, e-mail and collaboration tools can be "plugged" together in desired configurations to allow them to collaborate thereby attaining added functionality.

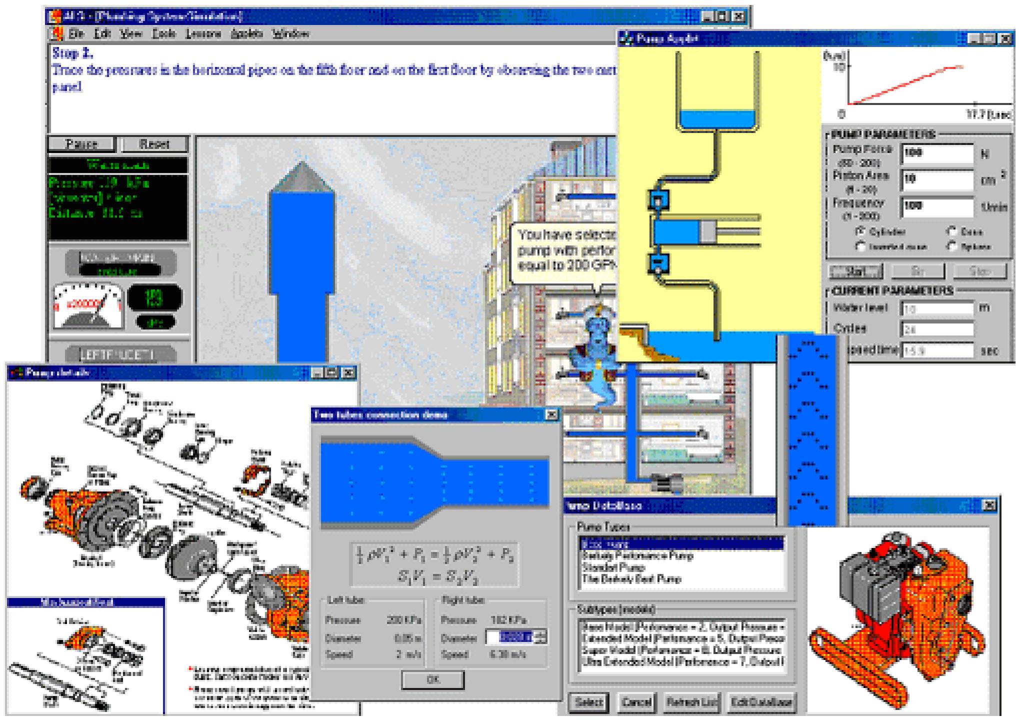

Fig. 1 The module **"Plumbing system"** enables a learner to explore the operation of a building's plumbing system, as well as relevant scientific and technical principles and laws. The student can interact with the system and change virtually every parameter. For instance, the student can change the height and diameter of the water tower, diameter of every pipe, etc. He/she can open faucets and see how the water level drops down. To fix the problem of water shortage on the top floor the learner is able to add another pump to the building's plumbing system (at the bottom of the building). This pump can be selected from a real online catalog (bottom right). By clicking on the pump, the student can open an exploded view of the pump and explore the design of its component parts (bottom left). The interactive simulations of a water pump (top right) allow the learner to study the relation between force and pressure, Pascal's principle and learn what parameters affect pump performance. The virtual experiment (shown in the center of the bottom) is designed to foster the understanding of Bernoulli's principle.

ALSuite *Simulations* (complex Java applets with associated HTML/XML parts and scripts) provide students with powerful tools, enabling them to (1) actively participate in modeling and virtual experimentation, (2) observe the physical processes at different levels, i.e. macroscopic, mesoscopic, and microscopic, and (3) analyze constraints between relevant parameters. Incorporated into each simulation are both help files and an online resource, which provides information and explanations of pertinent scientific theory.

The simulations are based upon real-world processes and objects. Virtual experimentation and modeling enable the learner to explore fundamental principles behind a familiar real world situation and bridge the gap between the abstract and tangible aspects of a particular scientific/technical principle. This helps students who are practical thinkers to grasp the relationship between science and math abstractions and observable phenomena [5]. Students with disabilities, for whom real hands-on experimentation is inaccessible, can experience and investigate the environment via virtual experimentation.

Data acquired from virtual experiments are sufficient to plot graphs and diagrams or analyze relationships between process parameters.

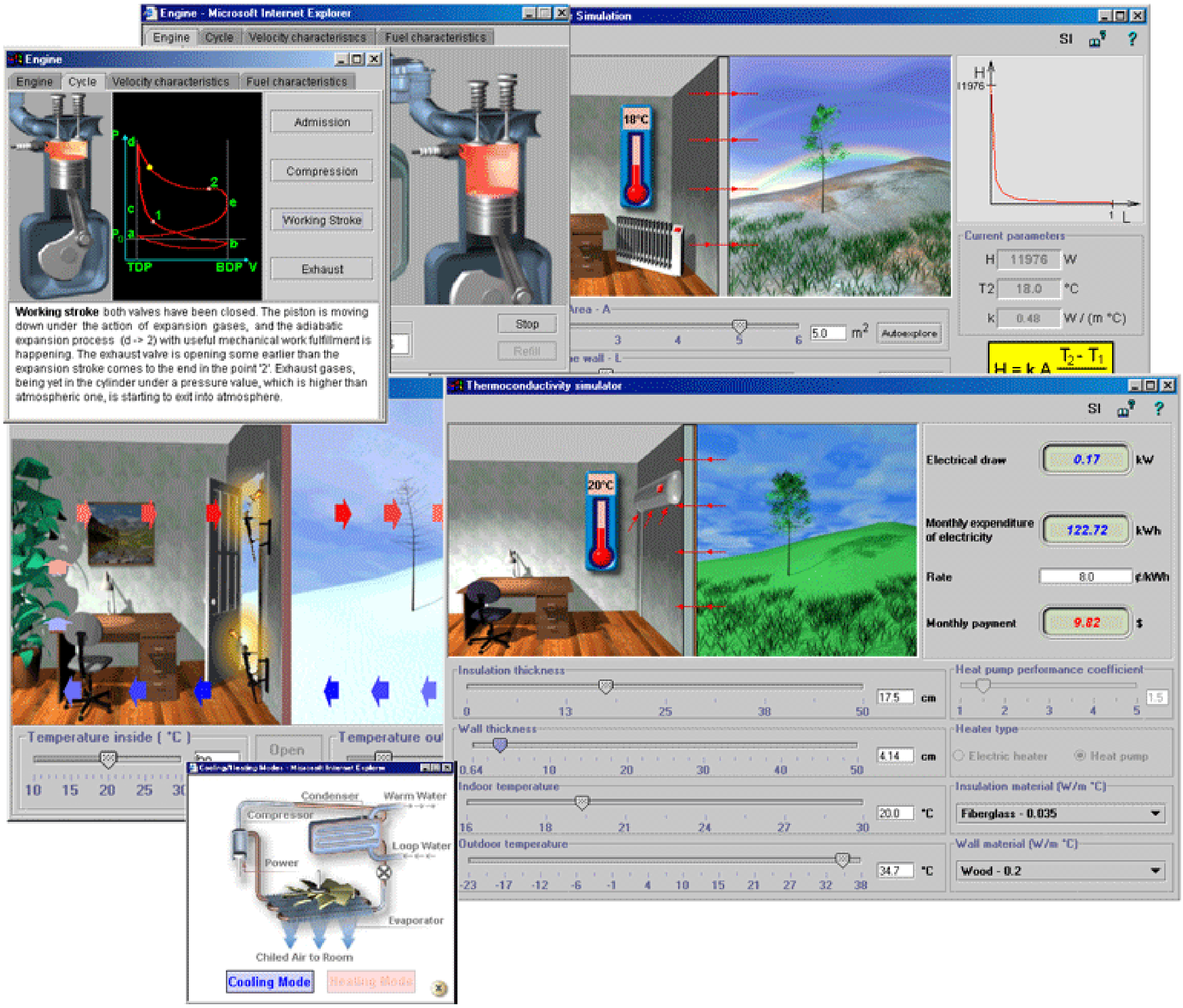

Fig. 2 Four virtual experiments, shown above, are designed to explore heat, temperature and energy conversion subjects. The ***Automobile engine*** simulation helps students understand the physical principles and laws on which the operation of a four-cycle internal combustion engine is based. Students can explore factors that affect engine efficiency. The bottom left simulation illustrates that warmed air rises and cools as it expands. The learner is able to explore how this process depends on temperature inside and outside a room. The two right simulations allow the student investigate how the thickness and material composition of an external wall as well as temperature difference affects heat transfer and losses. It is useful for the discussion of energy conservation and cost effectiveness of investing money into good house insulation. The animation in the very bottom illustrates the operation of an air conditioner and heater. In these and most other simulations a student can toggle between the American (British) system of units and the International system (SI).

ALSuite is comprised of Simulations, Virtual Experiments, Interactive Lessons, a Problem Solving Tutor, a scriptable and animated Instructor's Assistant, ancillary tools, and more. The figures below illustrate some of ALSuite components and activities.

The current version of *Active Learning Suite* includes the following modules:

- Thermodynamics
- Fundamentals of Wireless Communications
- Telephony* *(both wired and wireless)*, and
- Fluid Mechanics
- Fiber Optics
- Golf Mechanics*

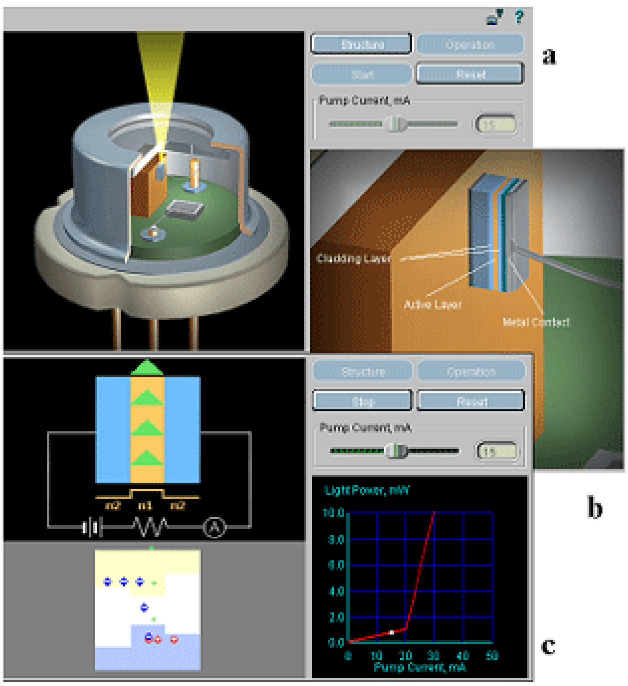

Fig. 3. Screenshot fragments for the simulation that is designed to present **Laser Diode** (LD) construction, operational principles and the physics behind it. From a general view, the simulation brings the student inside a LD (**a**). Then semiconductor laser chip can be zoomed (**b**) in order to visualize and study its double heterostructure and the functions of each part. Clicking on the "Operation" button opens a panel with a schematic picture of the key layers (**c**) that enables the student to learn and understand the operation of a LD and its link with fundamental optical laws, interatomic processes and quantum concepts. The graph on the right displays how altering pump current affects the light output.

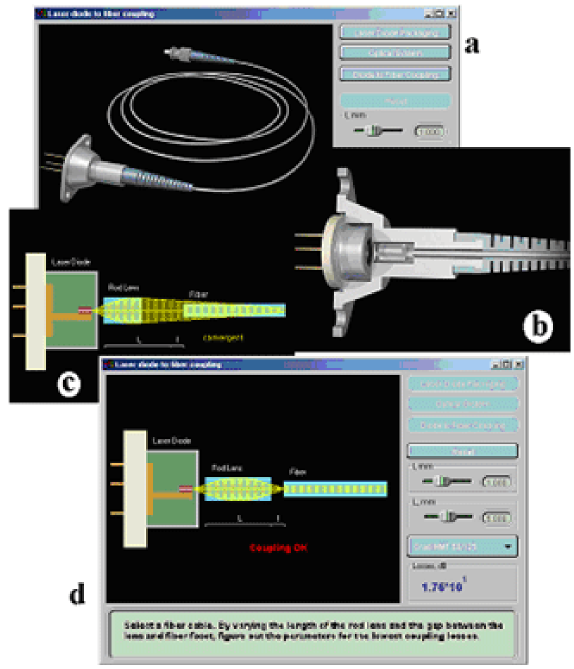

Fig. 4. This virtual experiment "**Diode To Fiber Coupling**" enables a student to explore the coupling unit conditions required for transmitting a laser beam emitted by laser diode into a fiber cable. The external design (**a**) and internal structure (**b**) of a laser diode package can be displayed. During the experiment (**c** and **d**) the student can select various fibers from an online catalog and examine how modification of the rod lens properties and the parts arrangement affect the process and losses. He or she can then be asked to determine the unit configuration for a specified optical cable that will provides minimum loss.

ALSuite is intended for problem-based learning and "learning-by-doing" [6-8]. The problems and virtual experiments in *ALSuite* are designed to challenge learners to develop effective problem-solving and critical thinking skills. This enables the learner to discover the connections between scientific theory and concepts and their practical applications in technology.

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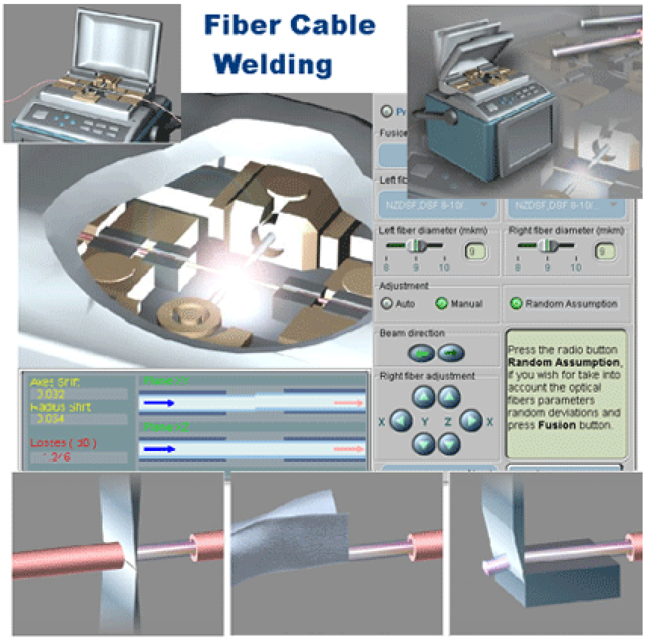

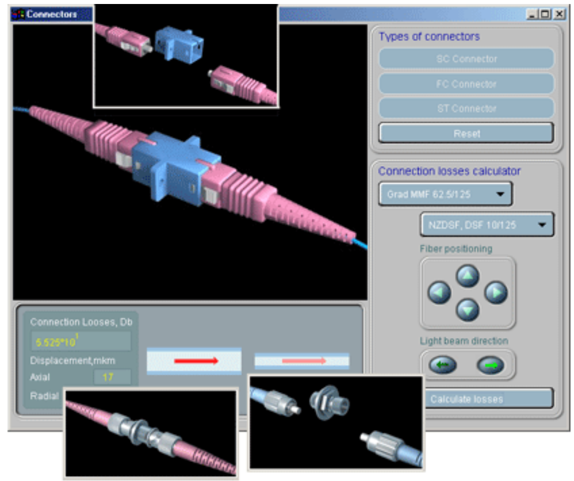

Fig. 5. The virtual experiment **Fiber Cable Welding** is designed to introduce to students, in detail, all steps of a welding process, welding equipment, and factors which affect the quality of welded cable and signal losses. The learner is able to explore all stages of the preparation phase, select the cables for welding either from a list of standard industrial products or set up customer cable parameters. In the Fusion phase, he/she can launch an automatic Fusion Splicing or adjust the cables manually and measure the losses if the adjustment was not perfect.

Fig. 6. The virtual experiment **Connectors** enables the student to learn pros and cons of different types of connectors. He/she is able to connect various cables, adjust them and measure losses in both directions.

The *ALSuite* software implements technologies that can provide instructional opportunities in many ways, whether at a campus/school (traditional teaching), at home (warm-ups, post-class tasks, or self-learning), in a corporate setting, or through distance learning. ALSuite helps teachers meld advanced emerging technologies with science and inquiry content, processes, and skills as defined by the *National Science Education Standards* of the National Research Council [9], and the *Benchmarks for Science Literacy* of the American Association for the Advancement of Science [10].

The multilevel nature of the modules and a flexible format make ALSuite suitable for both introductory and advanced courses and for the wide variety of students' backgrounds and learning styles including self-learning.

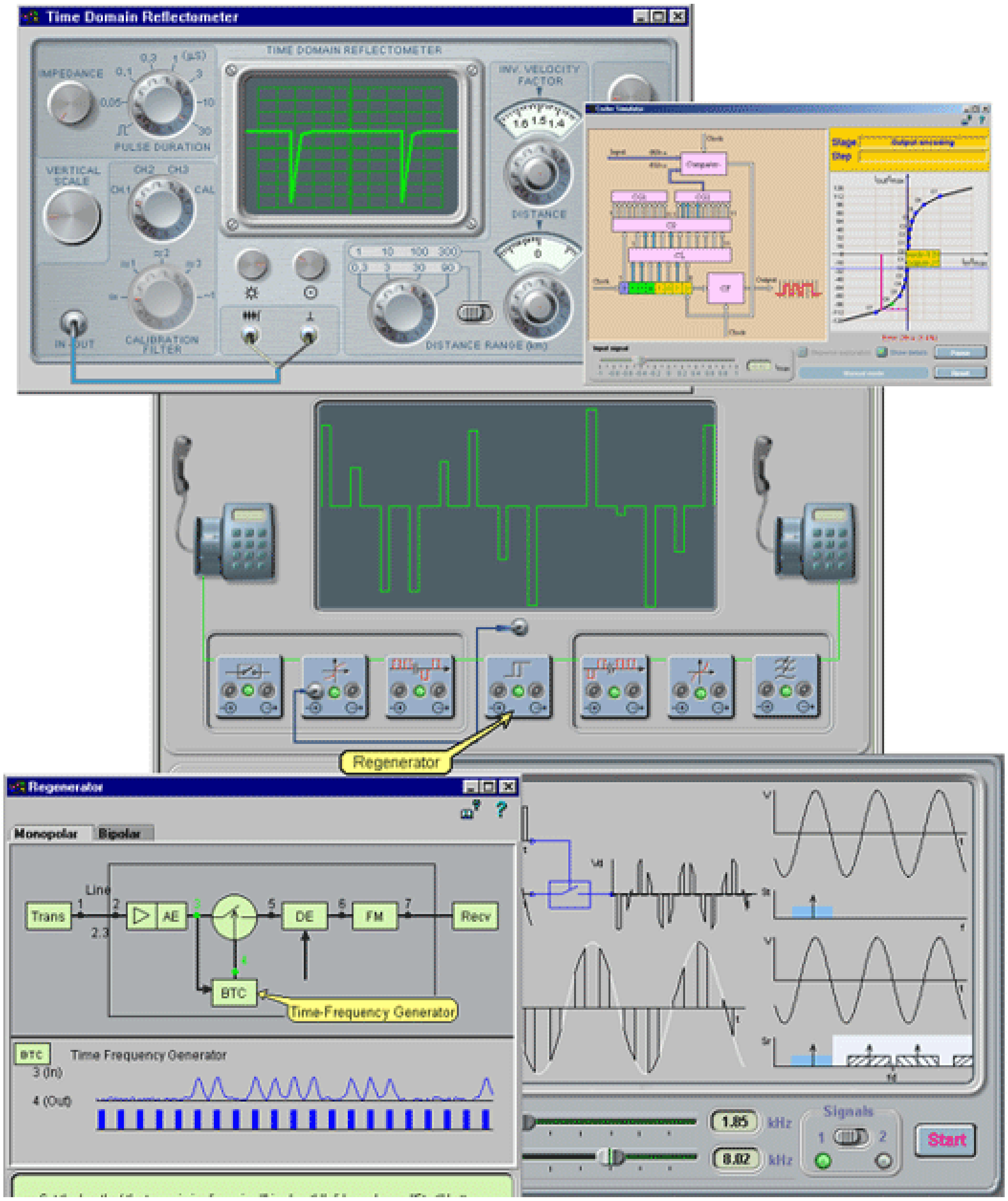

Fig. 7. The simulations on the right are designed to assist learners in exploring the architecture and operational principles of a wired telephone system and its parts. The simulation in the middle presents all major devices that form a communication track as well as input and output signals for each device. A click on a device icon launches the second level program that simulates the design and operation of the chosen device (Regenerator- bottom left and Non-linear decoder – top right). It enables the learner to fully explore the device functionality and structure. The embedded tool enables the student to digitize graphs and convert them into tabular data. The bottom right simulation visualizes all sequences of the processes occurring during the voice transmission from one subscriber to another. The student is able to trigger the simulation screen study into a display of a virtual oscilloscope and examine signals in detail. The virtual Time Domain Reflectometer (top left) allows a student to analyze signals and master the use of the apparatus for tasks in the field.

ALSuite software can be run from:

- Web site over the Internet,
- a server via a local school or corporate network,
- CD, or hard drive of a stand-alone computer.

ALSuite modules and components are compliant with SCORM and compatible with major learning management systems.

The ALSuite modules have been tested at numerous high schools, two-year community technical colleges, and four-year colleges and universities. Teachers' and students' feedback was very positive; they like the interface as well as the ability to vary parameters in a simulation to see immediate outcomes. One student, a paraplegic, made the comment that the simulations helped him understand the principles of fluid flow for the first time. He also commented that the COMPACT modules allowed him to participate on an equal footing with his fellow students unlike some activities in which he was more physically challenged even with accommodations made to permit him to fully participate

Preliminary quantitative results obtained in several two-year and four year-colleges and high school have shown an 18-25% increase in student performance and understanding.

Piloting a Russian version of the ALSuite modules with Russian students at three academic levels from high school to university, have demonstrated a 30-35% performance improvement compared to students in control groups. 85% of the Russian students who used these materials also expressed their excitement over their use of ALSuite tools.

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