Electronic distiller to improve learning processes in natural science laboratories

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Abstract. With the continuous advance of technology, new challenges arise in the face of innovative learning models and their theoretical-practical representation, in which we seek to strengthen effective teaching methods and maximize academic and experiential performance. Therefore, this article describes the development of an electronic distiller for basic natural science laboratories as a result of the research process, which allows teachers and students to perform experimental practices by means of simple distillation. The team developed, involves the concepts of Electronic and Systems Engineering, to improve the efficiency of the simple distillation process, solving needs in terms of assembly time and resource utilization, and optimizing the learning experience. This allows for automatic control of the boiling point of the substances and the quantity of grams to be distilled as the final product. This, thanks to the instrumentation and control modules that interpret the sensor signals, in order to control the actuators such as, the heating, pumping and cooling water system. The processes are visualized thanks to an Android graphic interface application, which allows monitoring and configuring the Setpoint of the measured variables.

1. Introduction
Basic sciences such as Biology, Physics, Geology, Mathematics and Chemistry, seek to understand the phenomena present in nature and in some cases replicate them, thus deciphering laws that satisfy this end. Linus Pauling defines chemistry as the science that studies substances, their structure, properties and reactions that transform these into other substances in reference to time [1]. However, in the specific case of a student, the interest in understanding these concepts, replicating them through methods used for more than 15 years, is increasingly complex. The sequence of teaching and learning lies in the selection and use of means that among others allow the student to interact, visualize and manipulate their learning context, to build bridges between theory and practical experience [2]. Therefore, providing the student with a way to become familiar with this bridge is one of the main foundations of any learning method.

Understanding the concepts that encompass chemistry from reality has become a challenge in both the basic and higher education cycles; the lack of evolution in the use of theoretical-practical bridges, in comparison with new tools embraced by other branches of science, generated a need in view of the fascinating technological developments of this century.
Hence, that incorporating “Investigación, desarrollo e innovación” (I+D+i) technologies focused on pedagogical processes, reveals a new alternative to face challenges in educational models. Although technologies such as augmented reality, virtual reality and Information and Communication Technology (ICT) have been involved in these processes, very few educational establishments have become involved.

On the other hand, engineering is a multidisciplinary practice based on the above-mentioned sciences, applying concepts to develop technologies capable of satisfying needs and solving problems, providing an efficient and productive management of the resources used. Therefore, all these new technologies that have evolved the way of teaching and learning, are a product of engineering, so much so, that ICT are based on software engineering, computing, among others.

The American Institute of Chemical Engineers (AIChE) defines in [3] Chemical Engineering as a profession in which knowledge, such as the case of basic sciences such as Mathematics, Chemistry, among others, is acquired through study, experience and practice. In order to apply it in the development of economic ways to use materials and energy for the benefit of humanity.

Education is undergoing major changes influenced by the advance of ICTs, which have generated educational resources in all areas of knowledge. This has led to the emergence of what are now known as virtual laboratories, which are a safe and easily accessible form of education. They allow real experiments to be carried out through the Internet, being tools that support classroom teaching [4], and an ideal complement to distance education [5]. Although one should not make the mistake of thinking that this form of teaching can completely replace face-to-face learning.

The “Laboratorio Tradicional” (LT) or hands-on allows the direct manipulation of the equipment and devices, through observation and experimentation, in which the student develops and optimizes his cognitive abilities and practical skills [6] necessary in the learning of Chemistry and Physics. Therefore, implementing I+D+i technologies developed through engineering helps to awaken a new interest in acquiring learning experiences.

In this sense, the learning and teaching of chemistry with new technologies is having a strong growth trend, which leads us to think about what advantages can be offered by innovating these technologies to make a significant change in the student. On the other hand, it has prompted profound changes in the curriculum of some curricula. Some cases are exposed by [7]: 1) in Hungary, there is no science without communication technology; 2) in the Czech Republic, where a combination of Chemistry and Computer Science has been implemented for undergraduate students; 3) in India, where a general evaluation of Chemistry Education has been made; 4) in Ireland, mainly in Organic Chemistry through the program Organic Chemistry in Action.

According to the above, it can be reflected as one of the objectives that have been pursued with the incorporation of new technologies in education, is to optimize the student's attention and achieve learning that adapts to existing needs. Therefore, this research proposes the engineering development of an electronic distiller to improve learning processes in simple distillation in natural science laboratories.

2. Simple distillation

Distillation has been a widely used separation technique in the industry and in organic laboratories around the world, so it is necessary to analyze and study the performance of the most common methods: Simple Distillation and Fractionated Distillation. Distillation bases its separation efficiency on the differences in vapor pressures, or boiling points, of two or more substances in solution, since the technique consists of boiling the more volatile substance and recondensing it in a different vessel than the initial one [8]. Therefore, substances with close boiling points are more difficult to separate by this method [9]. However, a disadvantage present in the distillation process is the low efficiency when trying to separate substances with a very high boiling point and also those present with low concentrations in
large volume carriers [10]. This has made it challenging to achieve a quality that can be considered high, even using non-linear controllers to do so [11].

This is because distillation is not an equilibrium process, since the mass is continuously removed from the system, it is based on states of liquid-vapor equilibrium, the boiling temperature, since the vapor phase is only removed when this equilibrium has been reached. Such balances happen to each other because the composition of the original liquid changes continuously [12].

In simple distillation the vapor is removed from the liquid sine and immediately passes into the refrigerant where it condenses and then the distilled liquid is collected. Using this procedure, mixtures of two components with a difference of 30-60° can be separated by repeated single distillations [12].

![Simple distillation assembly](image)

**Figure 1:** Simple distillation assembly [13]

### 3. Methodology

This research is based on the methodology set out in [14], which in turn is focused on the ICONIX software development method that is halfway between a Rational Unified Process (RUP) and an eXtreme Programming (XP). Its objective is based on the fact that each requirement is identified with some use case and in this way, to be able to verify in each instant of the system if the requirement has been fulfilled satisfactorily.

The ICONIX methodology is structured in four phases as described below:

- **Phase I – Requirements Analysis:** Collect information related to the research in books, documents and articles, as a basis or foundation for its development, decision making and generalities of the distillation process.
- **Phase II – Analysis and preliminary design:** Design a logical and organized structure of the different modules and the functions that each one must perform to obtain the final product.
- **Phase III – Design:** Design the modules in charge of operating each function in the system, such as the instrumentation module, which is responsible for operating, controlling and supervising the modules that make up the distillation process. As well as the heating, cooling and pumping modules, which allow the simple distillation process to be carried out.
- **Phase IV – Implementation:** Carry out the necessary tests to validate the correct functioning of the equipment in each of its stages, through the supervision of chemical engineers for the analysis of the results obtained, corroborating the fulfilment of the objectives previously set.
4. Results
The following is a description of the results obtained in the course of the research to meet the objectives set and to implement the selected methodology.

4.1. Requirements Analysis:
Examining the needs of the traditional method used to carry out simple distillation, the following four main problems become evident: a) Time and difficulty in carrying out the assembly, b) Fragility of the materials when handled by the students, given that most of them are made of glass, c) Deficiency in the use of resources such as the water used to cool the substance obtained, d) Difficulty in controlling the temperature of the substance. For this reason, it is necessary to implement innovative methods to solve these difficulties in natural science laboratories.

4.2. Analysis and preliminary design:
Once the existing difficulties in simple distillation processes in natural science laboratories have been raised, the preliminary design of the electronic distiller is started, which is divided into four main parts, such as: the heating, cooling and pumping modules, the instrumentation and control module in which the digital processing is carried out, the software and firmware, and finally the graphic interface application. This can be seen in Figure 2.

4.3. Design:
For the design of the electronic distiller, in its first stage, a K type thermocouple was implemented with a 10cm probe for temperature measurement, since it is made of a material resistant to industrial environments, resistant to corrosion and has an ideal probe length; which makes it suitable for the application in which it is going to be used. It also offers a temperature range up to 800°C and a resolution of 0.25°C. It is connected to the main microcontroller through the MAX6675 converter (see Figure 3a) which performs the compensation and linearization of the sensor response with an ADC, and the output data is obtained through an SPI communication.

The measurement of the distillate quantity is carried out by means of a 10Kg (extensometric) load cell (see Figure 3b), which varies its resistance according to the deformation it undergoes when a force is applied. It is connected thanks to the HX711 converter with a two-wire serial-data communication.
In the main data processing stage, a microcontroller of the ATMEGA family (ATMEGA328) was chosen, because it has a great variety of fast applications in the market, due to countless libraries developed freely by programmers around the world. This microcontroller is present in the instrumentation and control module, which receives the input signals from the sensors and user interface, processes them and makes the decisions pre-conditioned in the programming code (firmware).

The heater consists of a metal cylinder and on it a spherical base in stainless steel mesh that holds the distillation ball; a spiral-shaped thermal resistance of 120V AC/1000W located inside the metal cylinder was used, which is in turn connected to an AC power control board, which is activated by the control and instrumentation module. In the case of the cooling module which is used to recirculate the water, once it has fulfilled the task of condensing the vapor present in the distillation process, a 1300ml
storage tank is used, connected to a small DC water pump, with a flow rate of 3litres/min. Once the condensation has been carried out, the liquid that gained heat passes to a radiator, which is linked to a Peltier cell and a dissipator that extract the previously gained heat. Finally, it goes back to the tank for a new cycle.

For the last stage corresponding to the display and configuration of variables, we designed a graphic interface application developed in the MIT App Inventor 2 environment, dedicated to the creation of Android applications with .apk extension, which is connected via wireless connection (Bluetooth) to the instrumentation and control module, allowing the reception and transmission of data through the serial port of the main microcontroller.

In the drop-down menu of the application there are six options, in which you can see Water distillation, Alcohol distillation and Advanced distillation respectively. Figure 5 shows the windows that open when selecting one of these three options. In each of them, it is possible to monitor, track and display the reception and emission of data and variables involved in each process, such as the amount in grams, the temperature in degrees Celsius and the time spent.

![Figure 5: Graphic interface (a) options menu and (b) Alcohol distillation](image)

The development of the software constituted by the processing and graphic interface stage was named "AutodestLAB" and has software registration with the "Dirección Nacional de Derechos de Autor" (DNDA) with registration number No. 13-80-15.

4.4. Implementation:

Finally, in the implementation phase, the different tests were carried out in production in order to validate its functionality and performance. For the water pumping and cooling modules, their flow was verified through the entire system, in addition to monitoring the temperature in which the coolant was distributed by means of hoses, as shown in Figure 6. In addition, tests were carried out on the heating module, which consisted of verifying that the heat it supplies manages to reach the boiling point of the substance to be distilled, establishing voltage levels to reach the required temperature.
With the assistance of professionals from the Natural Sciences Department of the "Universidad Popular del Cesar" (UPC), several tests were carried out to obtain alcohol at an ambient temperature of 33°C, by means of mixtures of 200ml of 2-propanol isopropyl alcohol and 200ml of water, as well as water distillation tests, with mixtures of dye and water. In Figure 7, the behavior of the temperature control of the distiller can be seen, which allows an optimization in the energy consumption during the process, since the heating system is capable of regulating the power supplied by means of control signals, depending on the temperature sensed and required.

The tests previously exposed, allowed to validate the correct operation in production, of the electronic distiller for academic laboratories, evaluating performance, water and energy consumption, temperature control, amount of substance obtained and optimization in the execution time of the distillation process. In Figure 8, you can see the final result of the design and development of the equipment in its front part.
5. Conclusions
As a result of research based on the ICONIX methodology, the objectives set out for the engineering development of an electronic distiller to improve learning processes in simple distillation in natural science laboratories were achieved. To this end, difficulties in the practical process and their repercussions on the students' learning experience were initially analyzed, resulting in the need to develop equipment that would allow for the automation of the stages involved in simple distillation, such as; the heating and temperature monitoring stage, the cooling stage, and the stage of obtaining the final product. In addition, to identify that these traditional practices lead to a deficiency in the use of resources such as water and gas, to a misuse of time, given the delay in the assembly of the components, and to the difficulty in the sequence of learning and teaching in the student, due to the lack of interaction, visualization and manipulation of their learning environment.

Once the requirements analysis was done, the heating, pumping and cooling modules were designed and built, with which the required temperature regulation and the reduction of the equipment's energy consumption were achieved, by means of an ON/OFF control. In addition to the optimal use of water in the process, due to the fact that it was possible to significantly avoid its waste, when carrying out the condensation of the vapors, thanks to the implementation of a closed-loop pumping system. Going from a waste of approximately 90 liters of water for 30 minutes of process, to a need of only 1 liter of it in the storage tank, and that could be reused without any problem.

In addition to the above, an Android graphic interface application was developed, for the visualization, monitoring and configuration of process variables, through a screen on the computer. Finally, the different modules developed were integrated, with a robust, eye-catching, user-friendly architecture that requires minimum manipulation, in order to facilitate the development of the laboratory experiences and contribute to the effective training of the students.

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