Using the ELVIS II+ platform to create “learning is fun” atmosphere with the ISLE-based STEM approach

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Abstract. The topic of static and dynamic electricity is an abstract concept and relatively difficult for students to understand, especially in a case when the students were only taught about the electricity as a concept of electrical current, by means of the flow of electron, using analogy, without accompanied by practical experiments. This study aims to develop a lesson in the topic of dynamic electricity in an interesting and easy to understand approach using appropriate learning media that accompanied the abstract concepts with the real practical experiments. We used the equipment of ELVIS II+ (Engineering Laboratory Virtual Instrumentation Suite) from National Instruments to achieve the aforementioned goal. Props were designed to support various basic and advance dynamic electricity experiments. Selected topics relate to basic competencies 4.2 mandated by the ministerial regulation No. 24 in 2006 issued by the ministry of education and culture of the Republic of Indonesia (Permendikbud No. 24, 2016) exemplified by the capacitor charging and discharging experiments. It is expected that the activities would become interesting for the students since they were conducting the engineering process during the experiments that provided a fun learning. The more interesting part of the experiments was the understanding of concepts of science obtained from applying mathematics to solve differential equation problems. The application of mathematics appeared naturally when students constructing and solving the differential equations in order to understand the science behind the electrical phenomena. The most fascinating part for the students occurred when they can successfully proofed the solutions to differential equations with experimental results. Integrating the whole STEM (Sciences, Technology, Engineering, and Mathematics) components in the learning approach is proofed to be the key to the slogan of “learning is fun”. The experiment syntax followed the Investigation Sciences Learning Environment (ISLE) model so that the learning processes will develop thinking ability as prospective researchers in students.

Keywords: ELVIS II+, Learning is Fun, ISLE-based STEM.

1. Introduction

When the topic of electric current was delivered by a teacher in a classroom using analogies, most students were confused because electric current is an abstract concept that cannot be directly observed. For example, how the DC- and AC- electric currents flow in a wire through resistors and capacitors cannot be observed by naked eyes. Often, the teacher gives an analogy about electric current with water flowing from a high place to a low place that can drive a turbine. The analogy can help
understand the concept in general, but the analogy may be confusing because electric current can flow in the circuit that is a closed loop while the analogy is for an open loop. Then how can this analogy be understood for the flow of AC current? Of course, this will be confusing for students.

Learning using analogy methods can be used to provide an initial understanding of learning. The analogy method is a method for delivering a new topic by relating it to known information. However, to make students understand the concepts better, conducting experimental observations will be essential.

One indication that an experiment is considered beneficial to students is when students can find a good conclusion in the form of formulas, hypotheses, and models after the experiment. Based on the model obtained, students can predict other phenomena that will occur. Predicted phenomena can be tested by conducting experimental testing and this is observed as an interesting challenge for students.

If the phenomenon predicted was confirmed by the experiment, this will be a pleasant learning achievement for students. In order to heighten the impression, teachers can explain that the model can be applied for daily life. In other sides, if the results of the experiment are not in accordance with the prediction, teachers can encourage students by addressing that the experiment will be more interesting and challenging if students revise the model, analyze their prediction, or check the quality of the experiment. All of these processes can occur in several cycle which in the syntax of Investigative Science Learning Environment (ISLE) model, a constructive learning model for Physics introduced by Eugenia Etkina from Graduate School of Education of Rutgers University, The State University of New Jersey ([1],[2],[3]).

The main support in the ISLE model is experimental activities. In this study, the experimental activities use the NI ELVIS technology which can be applied to many topics in Physics specifically topics related to electricity and electronics. The familiarity to the cutting edge technology such as NI ELVIS is believed to give the students the skills that they need to face the 21st century challenges[4]. In this paper we reported a lesson study activity for the capacitor charging and discharging topics taught in class XII presented in Chapter 2 (Static Electricity) on the text book written by Marthen Kanginan [5]. The lesson was expected to help students reach the basic competencies 4.2 mandated by the ministerial regulation No. 24 in 2006 issued by the ministry of education and culture of the Republic of Indonesia (Permendikbud No. 24, 2016) ([6],[7]) for students in class XII which can be found in Table 1. The regulation were issued as an integrated part of the revision of Indonesian national curriculum known as Kurikulum 2013 or K-13 (see [8]).

| Original version | Translation Version |
|------------------|---------------------|
| 4.2 Melakukan percobaan berikut presentasi hasil percobaan kelistrakan (misalnya pengisian dan pengosongan kapasitor) dan manfaatnya dalam kehidupan sehari | 4.2 Performing the electrical experiments followed by presenting the experiment results (eg, charging and discharging the capacitor) and their benefits in everyday life |

The basic competence showed in Table 1 is an indicator of the achievement of the core competency 4 (skills) that students of class XII should be able to achieve, which contains process, reasoning, presenting, and creating in the concrete and abstract realms related to the development of what students learned in school independently and acted effectively and creatively, and being able to use methods according to scientific rules. The basic competency 4.2 is the skill that will support basic competencies 3.2 that is knowledge that students should possess to analyze electric charge, electric
force, electric field strength, flux, electric potential, electric potential energy, and their applications in various cases.

2. Method
In this section we will explain the lesson plan, the props used in the experiments, the relation between science and mathematics involved in the experiment, and pedagogical aspects addressed in the lesson.

2.1. Lesson Plan
The lesson uses the ISLE-Based STEM approach to learn about electric circuits that combining the similar methods done in previous studies (see [9],[10],[11],[12],[13] and [14]). Students will use the science/engineering process (see [1]) in learning the topic of capacitor charging and discharging. The experimental activities use the NI ELVIS technology as explained in the following subsection. Students were given preliminary tasks to set up a real and a mathematical model of a simple $RC$ circuit. They were also give a preliminary task to find an integral solution of some ordinary differential equations (ODE). The students were also given a manual on using the NI ELVIS Technology before conducted the experiments.

Several schematic diagrams of electric circuits were given to the students and they were asked to set up the circuits on the workstation using engineering process. Using the mathematical model found in the preliminary tasks, students were asked to find the solution of the homogeneous ODE. Using the data from the experiments and the theoretical solutions, students were asked to plot the results using the Octave/MatLab programming and compare the results. After the activities students were given a brief interview to gather information whether the lesson created the atmosphere of “Learning is Fun” for them and which part of the activities that they were considered as the most intriguing and enjoyable. The detailed explanation on the whole activities are presented in the following subsections.

2.2. NI ELVIS is a Cutting Edge Technology for Educational Props
The model of the ISLE-based STEM approach is based on experiments that certainly require props. National Instrument has a strong commitment to the development of education in the fields of electronics and instrumentation. In order to support the experiment, NI has developed an integrated device called ELVIS for electronic related experiment as showed in figure 1.

![NI ELVIS II + with protoboard owned by the STEM research center at Universitas Syiah Kuala](image)

**Figure 1.** NI ELVIS II + with protoboard owned by the STEM research center at Universitas Syiah Kuala

NI ELVIS is an integrated modular instrumentation platform that has features that are often used in electronic practicums such as digital Multimeters, Oscilloscopes, Function Generators, and Power Supplies. The main part of NI ELVIS hardware is a Bench-top workstation that can be installed with
several add-on application boards. In Figure 1 the add-on application board in the form of a breadboard prototyping has been installed in the workstation. In addition to the prototyping board, the STEM research center also has the add-on application board called DSDB (Digital Systems Design Board). Electronically, each feature will have a terminal or connector marked with a special label. For this experiment, the NI ELVIS facilities used are the Function Generator (FGEN), differential oscilloscope (A0 +/-, A1 +/-) with 100MS / sec capability, and the terminal for DMM.

2.3. Sciences and Mathematics (RC circuits and Linear 1st order ODE)

When students are given a physics problem, of course they will try to find out what the problem is and how to get the solution. In Figure 2a there is a closed-loop circuit arranged in series with a fixed voltage source E, resistor R, capacitor C, and a switch connected when t = 0. We invite students to investigate the circuit with a few questions. First, whether the system depends on time or not? If it is time dependent, what physical parameters are changing with time? When we are talking about the changing, the solution arises from solving differential equations. Before looking for a solution, of course you have to build a differential equation from the case. In Figure 2b, we intentionally display real components besides symbols to show that the schematic diagram and mathematics they will learn have real applications in everyday life.

![Figure 2. (a) The schematic diagram of RC circuit (b) Related real components for the symbols](image)

In order to build the differential equations, students should understand some fundamental concepts that work on the system. First, according to the Kirchhoffs Voltage Law or KVL, the sum of the voltages in the closed loop must be zero. This can be achieved if the $V_E$ countered by the voltage generated by $V_R$ and $V_C$. Thus,

$$\mathbf{\Sigma V} = V_E - V_R - V_C = 0 \quad (1)$$

The system uses a fixed voltage source $V_E = E$, resistor meets the Ohm's law $V_R = IR$, and for capacitor $V_C = \frac{Q}{C}$. The amount of electric charge stored in the capacitor $Q$ is equal to the integral of current flow with respect to time, $Q = \int I dt$. The task to develop equation (1) and the voltage formula of each component can be used as a preliminary task for students to develop a based knowledge to be able to take a practicum. Based on the voltage formula of each component, equation (1) becomes

$$\mathbf{\Sigma V} = E - IR - \int \frac{I dt}{C} = 0 \quad (2)$$

In order to eliminate the integral part, we have to take the derivatives of both sides with respect to time. A linear and homogeneous ODE (ordinary differential equation) is obtained as showed in equation (3).

$$\frac{dE}{dt} - \frac{dI}{dt}R - \frac{I}{C} = 0 \quad (3)$$
If students face obstacles, teachers encourage students to separate the variables and to realize the fact that the voltage is constant \( \frac{dE}{dt} = 0 \) during charging the capacitor. Students should be able to get to the following simpler equation.

\[
\frac{dI}{dt} = -\frac{dt}{RC}
\]  

(4)

The ODE solutions can be obtained based on the knowledge of integral solutions constructed during the preliminary task. Since the values of \( R \) and \( C \) of the components are constant, students can reach the following solution.

\[
I(t) = Ae^{-\frac{t}{RC}}
\]  

(5)

When \( t = 0 \) the current flows maximally because the capacitor is still empty \( (Q = 0) \), so that the initial current depends only on the resistor value and voltage \( I(t = 0) = E/R \). It can be used as an initial condition in order to obtain a current flowing solution.

\[
I(t) = \frac{E}{R} e^{-\frac{t}{RC}}
\]  

(6)

After students have struggled to produce solution (6), the visualization of the solution will be more impressive to students. The complete solution can be plotted using octave or excel by providing current source voltage and electronic components values. According to the STEM approach, the mathematics learning should be inclusive by applying the mathematical solutions (6) immediately. The learning atmosphere will be even more fun if the results of the plotting confirm the experimental result.

### 2.4. Engineering Process and Affective Ability

The use of the latest technology in learning is considered fun and preferred by students and it is more fun if they are involved in the engineering process. Engineering syntax consists of ask, imagine, plan, create, and improve. Simple activities following this syntax can be considered part of the engineering process, for example, measuring the value of an electronic component, figuring out the physics behind the process, and then, by using the available props, doing the measurement and subsequent measurement, as well as improvising.

![Figure 3](image)

(a) Measuring resistor values (a) and capacitors (c) using DMM integrated in ELVIS and measuring the results of resistors (b) and capacitors (d)

ISLE does direct students to be more active in conducting investigations without detailed instructions. But exceptions can be applied when using technology. A brief manual that guides students on how to assemble tools can be given to the students rather than let them do unguided trials that will risk the equipment for being damaged. In order for students to be more familiar with the equipment, the activity starts with simple application using the DMM facility to measure resistor values (Figure 3a and 3b) and capacitors (Figure 3c and 3d).
For the time-dependent experiments, students need to know the function of generators and oscilloscopes. Based on the preliminary task on learning resistors as voltage dividers, students were asked to design experimental circuits that were able to produce square signals whose amplitude was half of the initial amplitude produced by the generator function. The expected schematic diagram is showed in Figure 4a. A pair of resistors are arranged in series and integrated into the NI ELVIS workstation as showed in Figures 4b and 4c respectively.

![Schematic diagram](image1)

**Figure 4.** (a) The schematic diagram on how to use the FGEN and Oscilloscope with a resistor as the voltage divider (b) a closer look of dual resistor plugged to the prototype board. (c) The whole component and prototype boards put on the NI ELVIS workstation.

![Prototype board](image2)

**Figure 5.** (a) The panel of Function Generator and (b) The Oscilloscope Display
3. Results and Discussion
The result of the simple experiment is to understand the functions of generators and oscilloscopes to produce a square wave amplitude that is half smaller than the input through project experiments. In Figure 5a, the function generator is set to be Vpp (peak to peak voltage) of 4 V and an offset of 2V so that the lowest voltage become approximately to be 0V. In Figure 5b, oscilloscope scale is set at 1V/div, so the blue line as the input signal has a value of 4V and the output signal showed as a pink area has an amplitude of 2V. When students have successfully run the experiment of the project, it means that they already have the skills to use technology NI ELVIS for the signal measurement.

Our goal is to do an experiment with charging a capacitor based on equation (6). To verify this solution, a measurement of the electric current is required. While to measure voltage it is easier by using our oscilloscope, how do we get the current measurements? The answer can be found by using the Ohm's law. So, instead of measuring current, we can measure the terminal voltage of a resistor passed by the electric current to be measured. So that from the current meter as showed in equation (6) it is easier to measure the voltage like equation (7)

\[ V_R(t) = I(t)R = \frac{Ee^{-\frac{t}{RC}}}{R} \] (7)

Students are asked to design an experiment by giving a capacitor C to prove formula (7). If they had understood the concepts, then the result of the expected design as showed in Figure 6a which is similar to the previous experiments in Figure 4, was obtained by only replacing one resistor component with a capacitor as showed in Figure 6b. After several trials, most students were able to get this result.

![Figure 6.](image)

(a) The schematic diagram of charging and discharging capacitor
(b) The R and C components in a series circuit

The following experiments were performed using the same signal source as in the experiment showed in Figure 4. The process of charging and discharging of the capacitor is seen clearly in Figure 7a. Associated with the theory of capacitor charging which is formulated in equation (7), Figure 7a was cropped in the period of charging the capacitor as showed in Figure 7b.

Based on our experience in teaching, one thing that is fun for the students to experience is their capability to prove the theory studied using the experiments or to use the experiment to reinvent the theory. Therefore, a small program is made using the Octave program to visualize the equation (7) and use the appropriate parameters in the generator and oscilloscope function panel. Students can be given...
a template of the octave program, showed in Figure 8a, by substituting the values corresponding to the experiments they are doing. One thing that really makes the atmosphere of learning is fun existed occurred when the results of plotting data based on the theory as showed in Figure 8b are verified with the experimental results showed in Figure 7b. By interviewing the students, we found that the students saw that the visualization is the most intriguing part of the experiment where they can prove the theory using their experiment data.

Figure 7. (a) The experimental measurement results for filling and emptying the capacitor (b) zoomed in-experimental results focusing on the capacitor charging period

```matlab
E=4;           %amplitude Vpp (FGEN)
f=20;          %frequency Hz (FGEN)
tf=1/f;        %convert to period
tf=tf/2;       %high state only
n=1000;
dt=tf/n;
t=0:dt:tf;
I=E*exp(-t/(R*C));  % solutions
plot(t,I,'linewidth',3,'color','red')
set(gca,'xtick',[0:tf/5:tf])
grid on
```

(a)  

Figure 8. (a) The Octave/Matlab code for the implementation of Equation (7). (b) The plotting result with respect to the parameters of the resistor, the capacitor, and the amplitude and frequency of the input signal

4. Conclusion
Carrying out experiments as mandated by Permendikbud No. 24, 2016 for class XII Section 4.2 of the charging and discharging capacitor was found to be very interesting for students participated in this study. NI ELVIS technology was very easy to use if aided by a few instructions. Investigations carried out in the ISLE model are more about building science or design knowledge, but for the use of technology, more technical manuals are needed. Math exercises done during experiments were intriguing especially when the results of mathematical models were verified with the experimental results that really made the "Learning is Fun" atmosphere existed.
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