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# Augmented Reality-based Mobile Learning System for Electrical Fundamentals

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**Abstract:** With the popularity of using mobile devices nowadays, students were not limited to use desktop or laptop computers for their learning. They used tablets or even smartphone to review lecture materials, complete assignments and attend online classes. This new learning habit allowed teachers to adopt latest technology in these mobile devices to facilitate teaching and learning, and the commonly adopted one was Augmented Reality. In this paper, an augmented reality-based mobile learning system was developed to improve students learning effectiveness and efficiency of electrical fundamentals. In the mobile learning system, students were able to understand the 3-dimensional electric field and potential of different charged objects, phasor diagrams of AC circuits, circuit analysis with different resistors and batteries arrangement, and experiment settings. Results showed that students were appreciate using the mobile learning system to ease their understanding of abstract concepts in electricity.

**Index Terms:** Augmented reality, engineering education, mobile learning, circuit analysis, electric field.

## I. Introduction

The popularity and advancement of mobile technologies have encouraged educators to develop more effective learning activities for students in various disciplines to enhance their learning interest and progress [1-3]. Through the use of mobile devices, learning environment is no longer limited by classrooms and students can learn and practice subject matters at any time and any place. Among various mobile app development, Augmented Reality (AR) is becoming a promising and stimulating tool for learning and can be effective when used in parallel with traditional methods [4-6]. AR technology generates virtual information (e.g. a 3-dimensional model, an animation or a video) which overlays into the real world. People can interact with these virtual objects to perform a particular task, such as viewing a 3D model, capturing a monster in a mobile game, providing annotations on a real object, etc. Several studies show that AR increases students' learning motivation as well as their academic performance [7-11]. By displaying the virtual information next to a real object, students can easily visualise the abstract and cognitive concepts which is not likely be observed by naked eye. Also, "visual materials provided by the AR application helped students to do the experiments" of first-year university science students was reported by Akçayir *et. al* [12]. Restivo *et. al* [9] developed an AR application for direct current (DC) circuit experiment for students enrolled in the 9th grade. The AR application generates a set of virtual circuit elements, for example, DC battery, lamps, DC motor and switch, and students interact with these virtual objects by placing them in different positions in a prescribed circuit printed on a cardboard. The configuration and reconfiguration can be easily and quickly completed by students for providing timely comparison. The use of this AR application increases students' satisfaction and engagement. Also, L-ELIRA was developed with an AR application for visualizing virtual 3D models of mechanical elements in Industrial Engineering course [8]. The authors reported that students "preferred the new notes with 3D additional information over traditional ones".

The concepts of electricity are abstract and cognitively demanding, which are not easily understood by students and visualized by drawings during lecture. Hence, the learning experience of students is not comfort and full of frustrations from their high school and university study. This was also observed in our College in two courses,

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namely Physics II and Basic Electricity and Electronics. Students have difficulty in understanding the concepts of electric field and electric potential due to various charged objects (e.g. linear rod, a ring, an area) which can only be measured their effect on charges rather than "observed" the field and potential in 3D interactively. Also, the current direction in a resistive network can only be measured with ammeter during laboratory session which hinders the learning effectiveness of circuit analysis in class. Experiments are also an important part of learning engineering subjects. Traditional paper laboratory manuals are difficult to give a pictorial view on how to set up the experiment with real devices and alert students on the safety in different stages of the experiment continuously. Hence, an AR-assisted laboratory manual with different applications like video, graphics, simulation, etc, will help to enhance students' laboratory skills and achieve a better correlation between theory and practice. Students' awareness of safety precautions will be raised by indicating threats (e.g. electric shock, breaking a wire, etc) during an experiment with AR applications.

The integration of AR technology and mobile learning will provide a better learning experience to engineering students in studying electric field, electric potential, AC circuit, basic circuit analysis, and performing experiments. Hence, a novel AR-based mobile learning system for electrical fundamentals was developed and used as an interface to assist in learning and teaching of a course "Physics II" to our Year 1 engineering students. The AR-based mobile learning system generates 3D model of the electric field and potential of different charged objects for real time interaction by students during class or self-study using their mobile devices. Students can construct an electric circuit using the AR markers provided in the mobile learning system for practising circuit analysis. Equations for solving this electric circuit will then be overlaid with the circuit diagram in the real world through mobile devices. With this technology, students can enhance understanding on the abstract and cognitive concepts of electric field, electric potential, and circuit analysis through the virtual multimedia content inside and outside classroom. Students can carry out experiments more easily and safely with this AR technology during laboratory sessions. This mobile learning system is not limited by time and place, so students are able to review the contents at their own pace, which promotes active learning as well.

The rest of this paper is organized as follows. Section 2 gives the framework of the AR-based mobile learning system for electrical fundamentals, and then concise description of different functions of the system follows. Section 3 described the results and evaluation. Finally, a conclusion is discussed in Section 4.

## II. Framework of the AR-based mobile learning system

The AR-based mobile learning system is designed to enhance students' learning experience and effectiveness in electricity-related contents. The system is developed by Vuforia engine which is the most widely used platform for AR development with the support for most smartphones, tablets, and eyewear. Figure 1 shows the interactive user interface of the system, which students can select different functions or viewing the teaching materials.

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**Figure 1.** Main menu of an interactive user interface of the mobile learning system.

The system provides four functions to enhance students' learning experience and effectiveness, and they are:

1. Electric field and potential: provide 3D models of electric field lines/ vectors and voltage of various charged objects.
2. Circuit analysis: students construct an electric circuit based on given AR markers for practising circuit analysis.
3. Phasor diagram: the relationship between phasor diagram and waveform in AC circuits are given.
4. Laboratory video: two to three minute-long videos explain how to conduct the experiments.

*2.1 Electric field and potential function*

An entire electric field and potential is difficult for students to visualise since it is time consuming to calculate the values of electric field and potential in different locations of a charged object by hand or even through computers. Hence, 3D models of electric field and potential of charged objects (e.g. point charge, electric dipole, ring, etc) were developed. Since the mobile learning system was embedded in the teaching curriculum of the course, students used their mobile devices to scan the lecture note with this AR symbol, AR, then the 3D models will be generated as shown in Figure 2. Students can rotate the model, change the separation of the electric dipole, and

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view different aspects like voltage or electric field vector. Figure 3 shows the electric potential of an electric dipole.

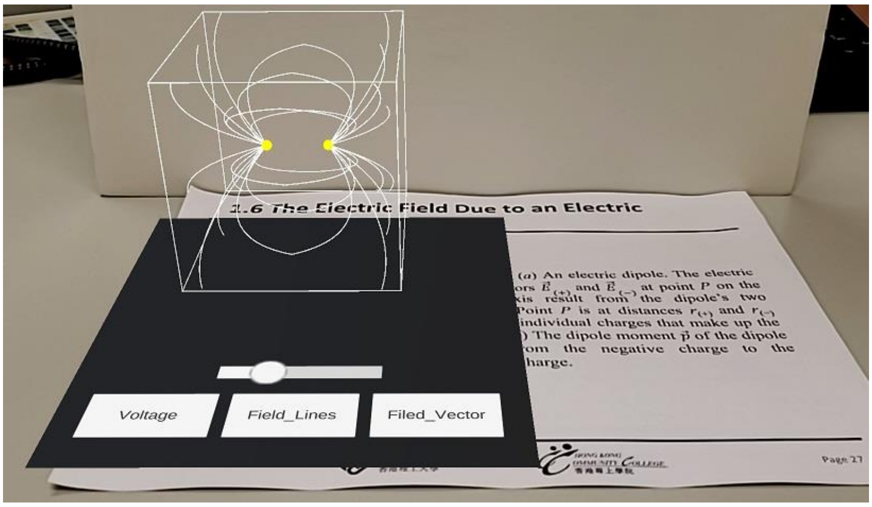


**Figure 2.** The 3D model of the electric field of an electric dipole displayed using smartphones after scanning the AR symbol on lecture note through the mobile learning system.

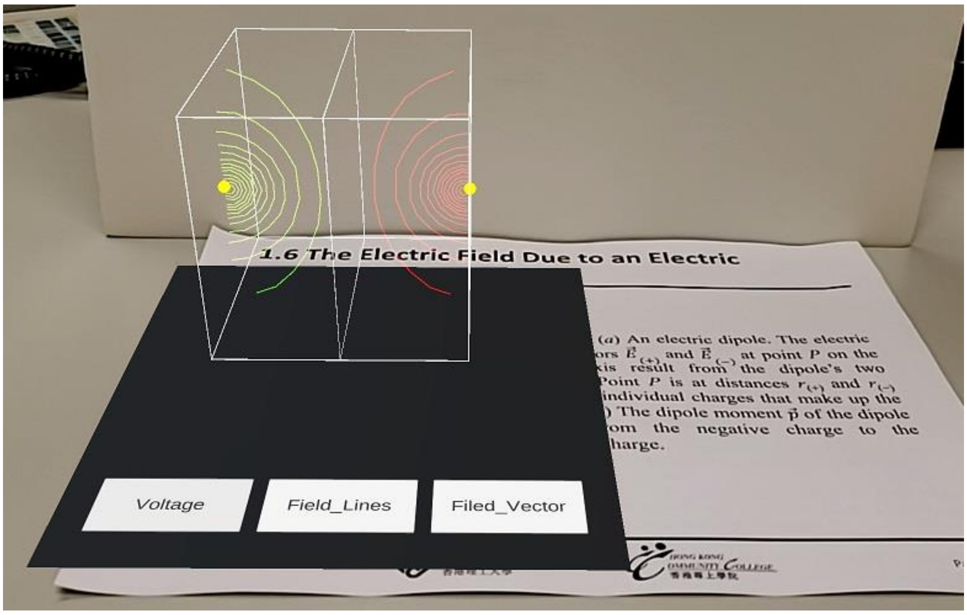


**Figure 3.** The 3D model of the electric potential of an electric dipole after clicking the "Voltage" button.

*2.2 Circuit analysis function*

Basic circuit theory (e.g. potential method) was given and practiced during classes in the course, Physics II. Due to the time limitations in classes and the broad coverage of course curriculum, it is good to provide additional examples with steps for solving different electric circuits such that students can cultivate their understanding outside classroom. Hence, the mobile learning system provides three circuit elements, namely, battery, wire and resistor, in AR markers format (Figure 4) such that students can construct any circuit based on these elements.

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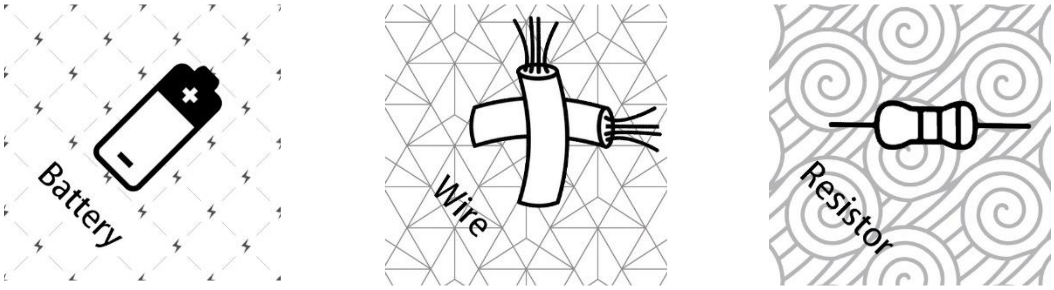


**Figure 4.** AR markers of three circuit elements.

Due to the limitations of computing power of mobile devices and AR technology, students were allowed to use at most two battery and two resistor AR markers for constructing their circuit. After construction, students use their mobile devices for scanning the circuit and the result of circuit analysis will be overlaid with the circuit diagram in real world through the mobile learning system. Figure 5 shows a simple circuit constructed by these AR markers. A more complicated circuit is also constructed for demonstration as shown in Figures 6 and 7. Hence, students can practice their problem-solving skill in circuit analysis at their own pace without time and location constraints.


**Figure 5.** A simple circuit constructed by AR markers.


**Figure 6.** A circuit using two battery and two resistor AR markers for construction.

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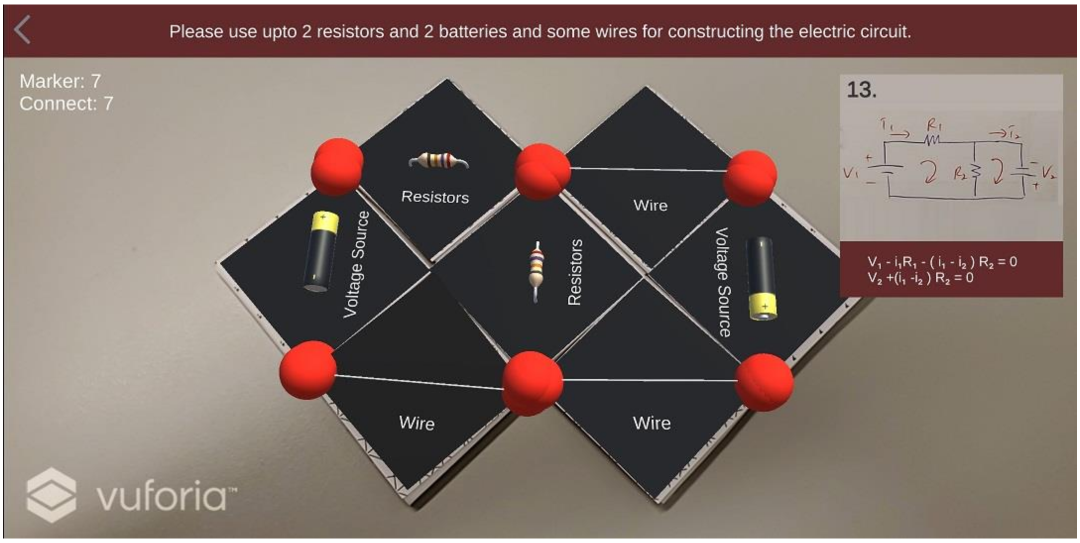


**Figure 7.** Result of circuit analysis through the mobile learning system.

*2.3 Phasor diagram function*

One of the hurdle for students to learn AC circuits is the relationship between time-domain waveform and phasor diagram. Hence, animations showing this relationship was provided in our mobile learning system. Students scan the AR markers in their lecture note to view the animations through their mobile devices. The animations were developed for the three basic electrical components (e.g. resistor, capacitor and inductor), AC power, and AC generation. Through these animations, students can easily visualise the relationship between AC sinusoidal signal and its phasor diagram which helps their learning. Figure 8 shows the animation of a capacitor with AC supply and Figure 9 shows the AR marker in the lecture note. Students can select either to view the capacitor's voltage or both voltage and current.

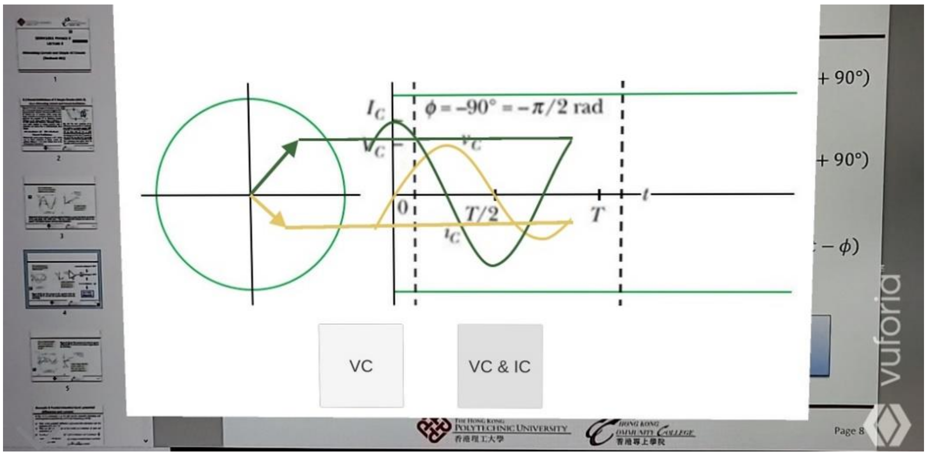


**Figure 8.** Animation of a capacitor with AC supply after scanning the AR marker.

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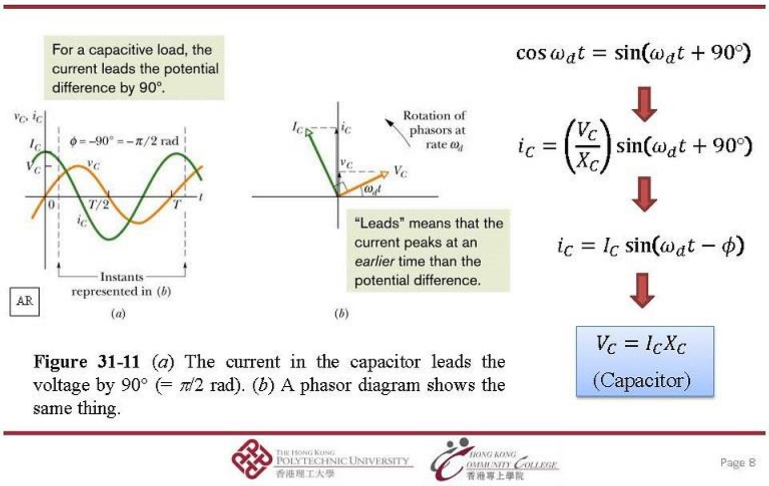


**Figure 9.** Screen shot of the lecture note with AR marker (capacitor's animation).

Lastly, an animation shows how the AC power is generated from sinusoidal voltage and current helps students to understand the AC power is also a sinusoidal signal (its magnitude is varying with time) instead of a constant value in DC circuit. Similarly, students can select different waveforms to look at as shown in Figure 10.

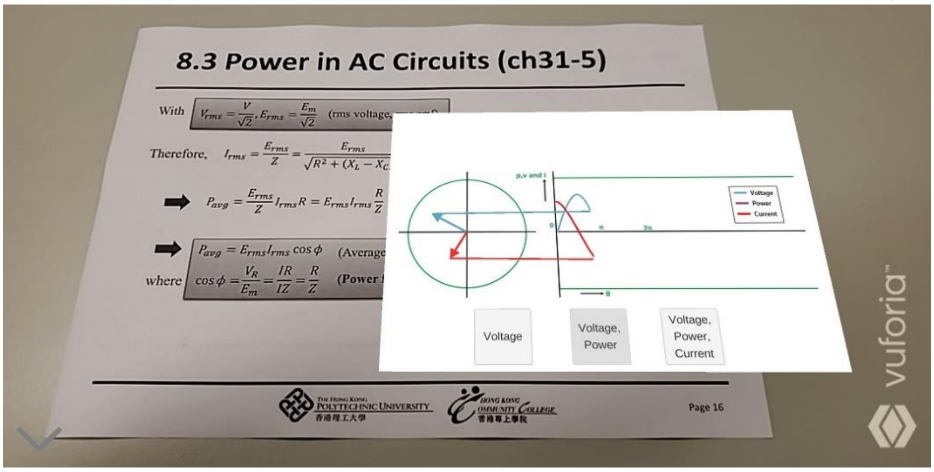


**Figure 10.** Animation shows the AC power generated from voltage and current after scanning the AR marker.

*2.4 Laboratory video function*

In the developed mobile learning system, two to three minute-long videos explaining on how to conduct the experiment were used as prepared by the course lecturer. AR markers were placed on different parts of the laboratory manual (Figure 11) of two experiments, namely, capacitance and Faraday's law of induction. Students can watch the videos again and again by scanning the AR markers on the laboratory manuals (Figure 12) by their mobile devices. This helps students to prepare the experiment before attending the laboratory sessions. Also, students can understand the operation of real laboratory apparatus under COVID-19 pandemic in recent years which led to the suspension of all face-to-face laboratory sessions. This may help students to develop their practical laboratory skills even under the pandemic situation by using only virtual experiments or simulations.

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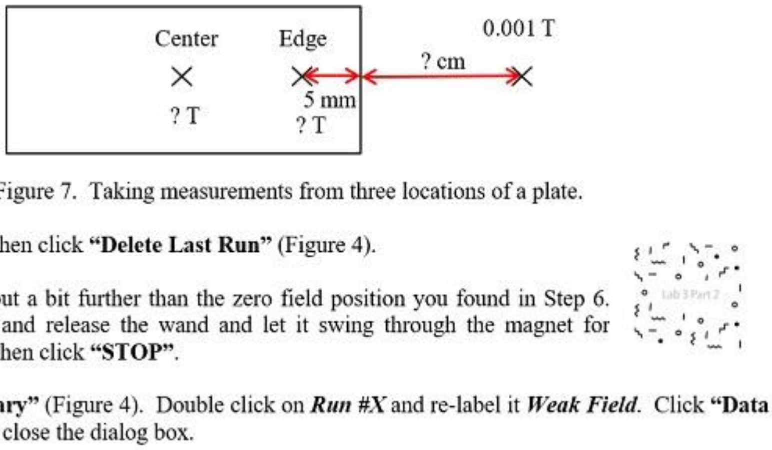


Figure 7. Taking measurements from three locations of a plate.

7. Click **"STOP"** and then click **"Delete Last Run"** (Figure 4).

8. Pull the coil wand out a bit further than the zero field position you found in Step 6. Click **"RECORD"** and release the wand and let it swing through the magnet for around 6 seconds. Then click **"STOP"**.

9. Click **"Data Summary"** (Figure 4). Double click on ***Run #X*** and re-label it ***Weak Field***. Click **"Data Summary"** again to close the dialog box.

**Figure 11.** Laboratory manual with AR marker for conducting Faraday's law of induction experiment.

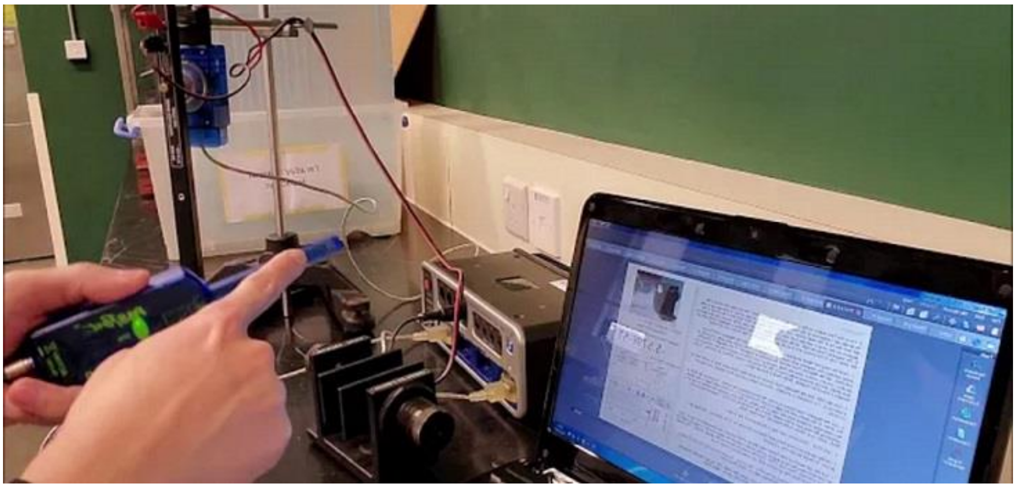

**Figure 12.** Example of providing the AR information (video).

## III. Results and Evaluation

The AR-based mobile learning system was developed for the course Physics II which covered electric force, field and potential, circuit analysis, capacitance, magnetic induction, and optics. The course was conducted in 3-class contact hours per week for 13 weeks with 6 laboratory hours. It is designed for first-year students of Associate of Engineering in the Divison of Science, Engineering, and Health Studies of Hong Kong Community College, an affiliate of The Hong Kong Polytechnic University in Hong Kong. There were two classes (A and B) in the course Physics II in 2020/2021 and 2021/2022 academic years. Class A was assigned as the experimental group and Class B was assigned as the control group randomly. The experimental group used the AR-based mobile learning system for electrical fundamentals, while the control group did not. Table 1 shows the student population in each group in different academic years of the course.

**Table 1.** Student distribution of Physics II in different groups and academic years.

| Academic Year | Experimental Group | Control Group | Total |
|---|---|---|---|
| 2020/2021 | 90 | 32 | 122 |
| 2021/2022 | 45 | 74 | 119 |
| Total | 135 | 106 | 241 |

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A statistical analysis (t-test) was conducted to determine the significant differences between the results obtained by both groups to measure the students' learning effectiveness in the course. The results revealed that there was extremely statistically significant difference between the performance in coursework and examination, and laboratory report of the experimental and control groups (Tables 2 and 3). Selected questions, which covered by the mobile learning system, from assignments, test and examination were used to study the performance in coursework and examination. Thus, the result shows that the AR-based mobile learning system has a positive effect on engineering students' learning effectiveness in electrical fundamentals and experiments.

**Table 2.** The t-test scores for learning effectiveness from the performance in coursework and examination of the experimental and control groups of all students.

| Variable | Group | N | Mean | SD | *t* | *p* |
|---|---|---|---|---|---|---|
| Performance in coursework and examination | Experimental | 135 | 286.45 | 38.15 | 3.7087 | 0.0003 |
| | Control | 106 | 268.29 | 37.23 | | |

**Table 3.** The t-test scores for learning effectiveness from the performance in laboratory report of the experimental and control groups of all students.

| Variable | Group | N | Mean | SD | *t* | *p* |
|---|---|---|---|---|---|---|
| Performance in laboratory report | Experimental | 132* | 81.08 | 14.85 | 4.5764 | 0.0001 |
| | Control | 104* | 72.83 | 12.23 | | |

*Students who did not submit laboratory report were removed.

A longitudinal study was also conducted to avoid cohort difference. The results also revealed that there was statistically significant difference between the performance in coursework and examination, and laboratory report of the experimental and control groups (Tables 4 and 5).

**Table 4.** Longitudinal study of the t-test scores for learning effectiveness from the performance in coursework and examination of the experimental and control groups.

| Variable | Academic Year | Group | N | Mean | SD | *t* | *p* |
|---|---|---|---|---|---|---|---|
| Performance in coursework and examination | 2020/2021 | Experimental | 90 | 284.12 | 35.33 | 2.4052 | 0.0177 |
| | | Control | 32 | 266.94 | 32.88 | | |
| | 2021/2022 | Experimental | 45 | 291.11 | 43.30 | 2.885 | 0.0047 |
| | | Control | 74 | 268.88 | 39.6 | | |

**Table 5.** Longitudinal study of the t-test scores for learning effectiveness from the performance in laboratory report of the experimental and control groups.

| Variable | Academic Year | Group | N | Mean | SD | *t* | *p* |
|---|---|---|---|---|---|---|---|
| Performance in laboratory report | 2020/2021 | Experimental | 87* | 82.91 | 16.25 | 2.8101 | 0.0058 |
| | | Control | 30* | 73.00 | 17.81 | | |
| | 2021/2022 | Experimental | 45 | 77.56 | 11.02 | 2.5538 | 0.0119 |
| | | Control | 74 | 72.76 | 9.23 | | |

*Students who did not submit laboratory report were removed.

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A questionnaire was designed to measure the effectiveness of mobile learning system as well as learning experience from students. The questionnaire consisted of 14 questions and used a 5-point Likert-scale: 1 – Strongly Disagree, 2 – degree, 3 – Neutral, 4 – Agree and 5 – Strongly Agree. Table 6 shows the questions and results of the questionnaire. The questionnaire was conducted online after the course was completed, and 42 valid questionnaires were received. In general, students expressed a positive attitude with the materials content (Q1–Q3) and usability (Q4–Q5). The effectiveness of the mobile learning system was appreciated by students (Q6–Q11) which enhanced their learning of abstract concepts in electricity and better understanding of the experiments. Overall speaking, the mobile learning system assisted students' learning the course contents and students had a good experience in using this mobile learning system (Q12–Q14).

The results are encouraging for adopting AR technology in engineering education. AR annotation and contextual visualization of abstract concepts in electricity improves students' perception and construct their knowledge [13]. The multimedia theory provides a good foundation to explain on how AR improves learning. As Mayer stated, "when words and pictures are both presented, students have an opportunity to construct verbal and pictorial mental models and to build connections between them" [14]. This can be observed in the better academic performance of students who have used the AR-based mobile learning system to assist their learning in the course Physics II. Besides, 3D visualization of electric field and potential, and animation of phasor diagrams link virtual information to electrical theories that students have learnt provides a better learning experience. This learning contextually with the mobile learning system helps students to construct their knowledge by relating new information with their personal knowledge through REACT [15]. REACT is an acronym that describes five strategies to result contextual learning:

1. *Relating*: link a new concept to something students already know
2. *Experiencing*: learning by doing, connect new information to prior knowledge
3. *Applying*: allow students to use the concepts in realistic and relevant exercises
4. *Cooperating*: students work in small group to share, respond, and communicating with peers
5. *Transferring*: students use their new knowledge in a new context or novel situation

The construction of circuits by AR markers deepens students' understanding of circuit analysis concepts. It relates students' past knowledge learnt in high school, provides relevant exercises to skill drill, and finally transfers this new knowledge to new situation like multi-mesh circuits. Furthermore, the use of short video clips helps students to understand how to conduct the experiments and operation of laboratory apparatus. This is especially important in recent years because of the suspension of face-to-face laboratory sessions due to the COVID-19 pandemic. As a result, the AR-based mobile learning system provides a better learning experience and an effective mean to study electrical fundamentals for first-year university students.

**Table 6.** Questions and results of the online questionnaire.

| No. | Questions | Mean value | Standard Deviation | Median |
|---|---|---|---|---|
| 1 | Teaching materials in the mobile learning system are nicely presented. | 4.10 | 0.68 | 4 |
| 2 | Teaching materials in the mobile learning system are well-organised. | 4.14 | 0.64 | 4 |
| 3 | Teaching materials in the mobile learning system are useful. | 3.98 | 0.77 | 4 |
| 4 | Augmented Reality (AR) application is stable (bug free or system suspension). | 3.93 | 0.80 | 4 |
| 5 | The mobile learning system is easy to use, even without written instructions. | 4.10 | 0.87 | 4 |

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| | | | | |
|---|---|---|---|---|
| 6 | Lecturer's explanations on the topics: electric field, potential and circuit analysis, are easier to understand by using this mobile learning system. | 3.93 | 0.80 | 4 |
| 7 | The mobile learning system helps me to understand how to conduct the laboratory. | 3.93 | 0.91 | 4 |
| 8 | Proper 3-dimensional figures visualization are shown correctly in the mobile learning system. | 4.19 | 0.73 | 4 |
| 9 | I think the materials in the mobile learning system will help me perform better in assignment, test and examination with questions related to electric field, potential and circuit analysis. | 3.83 | 0.92 | 4 |
| 10 | I can use AR markers provided by this mobile learning system to construct different electric circuit for learning. | 3.83 | 0.72 | 4 |
| 11 | I can know whether my answers are correct (e.g. circuit analysis) by using this mobile learning system. | 3.93 | 0.91 | 4 |
| 12 | I like using this mobile learning system to assist my study. | 3.88 | 0.82 | 4 |
| 13 | Using the AR technology in this mobile learning system is an enjoyable experience. | 4.17 | 0.75 | 4 |
| 14 | Overall speaking, I enjoy using this mobile learning system and shall use it frequently. | 3.83 | 0.81 | 4 |

## IV. Conclusion

The popularity of mobile devices has changed the learning and teaching habit of engineering education. Students are no longer limited by place and time for reviewing the teaching materials of different courses. With the advancement of AR technology and computational power of mobile devices, the abstract concepts in electricity (e.g. electric field and potential) can be easily visualized by mobile devices through animation and 3D models. In this paper, an AR-based mobile learning system was developed for improving university first-year engineering students' learning experience and effectiveness in electrical fundamentals through the course Physics II. Combing the multimedia theory and contextual learning theory in preparing the teaching contents, the developed mobile learning system assisted students' learning and understanding of experiments. Students perceived positively to the developed mobile learning system. The statistical results confirmed this observation. In the future, the developed mobile learning system will be improved based on the feedbacks from students and teachers, and extended to other courses in Electrical and Electronics Engineering programme.

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