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A GREEN ELECTROCHEMISTRY EXPERIMENTAL KIT: STUDENT'S ACHIEVEMENTS ON LECTROFUN 2.0

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ABSTRACT

The study aimed at developing and evaluating a simple green electrochemistry experimental kit named Lectrofun 2.0. Lectrofun 2.0 is an educational kit equipped with a module built with the criteria of user-friendly, cost-effective, and laboratory free. The basic concept of electrochemistry was introduced through a guided learning approach via the module. The objectives of this research were to (1) develop Lectrofun 2.0 module using green chemicals, recyclable and easily accessible materials and (2) evaluate the module effectiveness in terms of student achievement/understanding of the Electrochemistry topic. This is a Design and Development Research (DDR) using the ADDIE model as an instructional design model. The development phase involves the first objective of the study, while the evaluation phase involves the second objective. Total of 46 respondents of pre-post tests were involved in evaluating effectiveness of Lectrofun 2.0 in terms of student achievement/understanding of the topic. The findings showed that 73.9% of students from the treatment group showed 4-grade increment (from grade E to grade A). This study showed that Lectrofun 2.0 has a significant impact on enhancing learner comprehension of Electrochemistry topic, enjoyment in learning, and learning to care for the environment.

Keywords: green electrochemistry; chemistry; STEM education; teaching aid; soft skill

INTRODUCTION

The situation in the world has changed when the first case of coronavirus (COVID-19) outbreak occurred in December 2019. The World Health Organization (WHO) classified COVID19 as a global pandemic in March 2020 (WHO, 2020). Many countries issued strict protocols such as complete lockdowns in infected areas or regulations to facilitate social distancing to reduce and prevent the virus spread. It includes working from home, flexible working hours, or closing educational institutions.

It is reported that 370 million students of all ages from around the world are affected by closure of schools and universities (UNESCO, 2020). Therefore, all levels of educational institutions are forced to operate remote teaching into practice. Many creative temporary solutions benefited from the experiences of remote teaching, such as game-based learning (Fontana, 2020; Yang et al., 2020), project-based learning (Nerantzi, 2020; Yustina et al., 2020), and recorded teaching videos (Danjou, 2020; Dow et al., 2020).

Smith and Watson (2019) recognised that STEM (Science, Technology, Engineering, and Mathematics) should provide important skills and insights into alternative futures as ways forward for economic, social, and environmental sustainability and education. They believed if STEM education is approached through the critical and sustainability-focused lenses of EfS (edu-

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cation for sustainability), STEM can be harnessed in the service of the flourishing of humanity and the more than-human world. STEM module is a Project-based Inquiry Learning (PIP) approach. Four learning phases in this approach are; Inquiry phase, Exploration phase, Design and Experiments phase, and Reflection phases (Adnan et al., 2017). Many activities reported in recent journals involved STEM (Azman et al., 2018; Sharif et al., 2018; Permanasari, et al., 2021) and environmental conservation (Lin et al., 2018) and target enhancement of understanding science concepts.

Electrochemistry is an abstract topic to learn through conventional explaining and teaching techniques. It is because the limitation of naked eyes means one cannot see the flow of electricity and the movement of electrons or the process happening when a reaction occurs in the electrode (Johnstone, 1993). Besides, student understanding of electrochemistry topics, which are different from facts and scientific concepts, makes them have misconceptions in the learning process. Akram et al. (2014) showed that most students answered incorrectly when questions involved electrolysis and its mechanism. To provide students with insight into the concept "electricity in and chemical reaction out" in remote teaching, a fun and exciting experiment possible to run at home needed to be carried out (Fox et al., 2020). Therefore, students are able to witness the transformation of electric energy to chemical energy and vice versa.

Previous studies reported many ways related to teaching electrochemistry topics can be carried out through remote teaching such as multimedia module (Doymus et al., 2010; Osman, & Lee, 2014), board games (Kurniawan et al., 2017), and virtual laboratory (Hawkins, & Phelps, 2013). All these teaching methods, however, do not feature conduct of hands-on experiments feasible at home. Only a few studies report electrochemical experiments possible via remote teaching (Kuntzleman, 2019; Tan et al., 2019).

Tan et al. (2019) designed a hands-on activity named *electrochemistry designette* that incorporates design thinking to strengthen students' electrochemistry concepts. The electrochemical device consists of simple and familiar materials such as electrode pairs composed of Copper, Zinc, Aluminium, and Tin electrodes, along with rice wine and copper(II) sulphate ($CuSO_4$) solution as electrolyte, connected via staples, wires, and eyelets. The teaching aid was reported as successfully improving student ability to recall information, hence enhancing the learning experience.

Kuntzleman (2019) described how metal items found around the home were used in electrochemical experiments to create messages and artistic designs. The experiments were straightforward to set up and carry out by connecting a battery to a metal item on a piece of wet paper. A striking visual result was produced by observing the colour change on the damp paper. The experiments were related to the concepts in electrochemistry, acid-base chemistry, and thermodynamics.

These two alternative ways of remote teaching in electrochemistry experiment do not focus on determination of anode and cathode in electrolysis cell and galvanic cell, improvement of gas leakage during gas collection in conventional electrolysis cell and alternative green chemical to run high concentration of electrolyte experiment.

Therefore, it inspired us to enhance student understanding of electrochemical concepts with household items such as salt and vegetables, and embed STEM education in our research. Consequently, we took a challenge to design and develop a simple green electrochemistry experimental kit named Lectrofun 2.0. The design adopts alternative gas collection setup and alternative harmless green electrolyte. Two objectives in this study are development of Lectrofun 2.0 from household items and recycled materials and investigating its effects on student understanding of the concepts in the developed Lectrofun 2.0. These activities could also help students in rural areas and Third World countries learn science concepts despite the lack of apparatus, chemicals and appropriate laboratory space.

METHODS

This is a design and development research. Lectrofun 2.0 was used as teaching aids during the teaching and learning process of the treatment group. In contrast, the control group used the conventional method according to the specified form 4 chemistry syllabus in Malaysia (Kementerian Pendidikan Malaysia, 2018). The teaching and learning method of electrochemistry topic was the independent variable, while the dependent variable was student achievement in pretest and post-test of electrochemistry concepts.

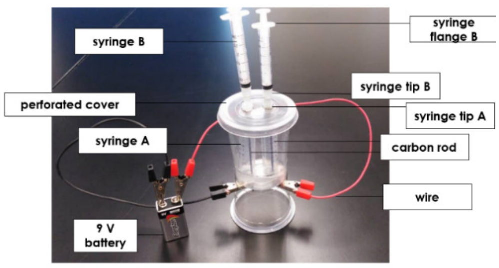
ADDIE instructional design model which involves Analysis, Design, Development, Implementation and Evaluation was used to develop Lectrofun 2.0. Lectrofun 2.0 is an experimental kit consisting of a module and apparatus needed for the electrochemistry experiment setup.

The process started with analysing problems encountered in schools around the world. The survey showed teachers lack resources related to home-based experiments in electrochemistry topic. Besides, when formal education is back after lockdown, schools especially in rural areas do not have adequate apparatus, chemicals, and laboratory equipment, as supported by a Malay mail report in March 2017 (Robertson, 2017).

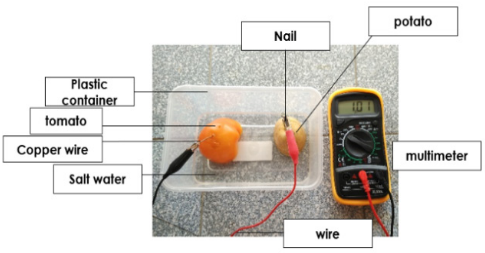
Lectrofun 2.0 was designed based on practical experiment of electrochemistry topic in form 4 (age 16) but simplified using green chemicals, recyclable and easily accessible materials (Kementerian Pendidikan Malaysia, 2018). STEM module was adopted as a reference in designing the Lectrofun 2.0 module.

In addition, the experiment setup was designed with the following criteria: (1) User friendly; (2) Cost-effective; and (3) Laboratory free. Low-cost materials such as salt, tomato, potato, pencil lead, syringes, nail, copper wire, aluminium foil, plastic container and plastic cup were used. The selection of materials used encouraged students to become more creative without relying entirely on the existing practices manual.

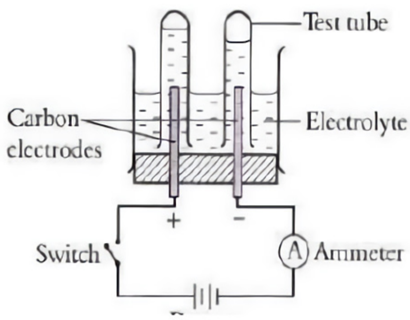
(a)



(b)



(c)



(d)

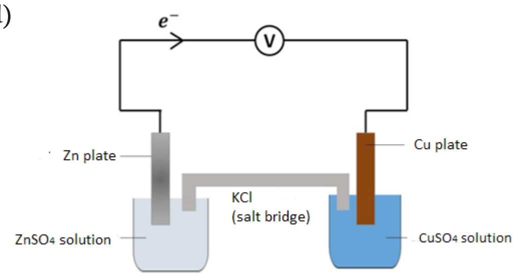


Figure 1. Lectrofun 2.0 of (a) Electrolysis Cell Setup and (b) Galvanic Cell Setup. Conventional Experiment of (c) Electrolysis Cell Setup (Low et al., 2016) and (d) Galvanic Cell Setup

Two types of development are explained in this section which are development of experimental setup and development of the module.

Development of experimental setup was done according to the electrolysis cell setup (Figure 1a) and the galvanic cell setup (Figure 1b). Some changes in electrolysis cell setup modified from conventional electrolysis setup (Figure 1c) are; (1) syringes as gas collection medium to replace test tubes; (2) plastic cup to replace beaker; (3) pencil lead as electrodes; (4) table salt, NaCl, as an electrolyte; and (5) food colouring solution as an indicator of chlorine gas presence. Conventional gas collection method by dipping a hand into harmful chemical electrolyte and closing the nozzle of a test tube using thumb is hazardous to students. Therefore, syringes are used to replace test tubes to facilitate gas collection. By pulling the plunger upwards, the resulting gas in syringe A will be sucked into syringe B. The gas test is done at the syringe flange B after removing the plunger. The utilisation of table salt, NaCl, as electrolyte gives advantages to run experiment of ion selection factor for discharge in anode and cathode at high concentration of electrolyte, which is usually learned in theory at school. Implementation of food colouring solution as an indicator of chlorine gas at the anode in a high concentration of electrolyte replaces damp blue litmus paper.

Meanwhile, modification of galvanic cell setup from conventional galvanic cell setup (Figure 1d) is; (1) potato and tomato as electrolytes; (2) salt water as a salt bridge; and (3) nail, copper wire and aluminium foil as metal electrodes.

Adaptation of four learning phases in STEM module is practised in developing the Lectrofun 2.0 module (Figure 2a). An experiment's objective was provided at the beginning of each activity. It is required to be achieved by students at the end of the experiment. This phase is known as the inquiry phase. List of materials and tools for each activity was provided in the module. Students were given opportunity to familiarise themselves with experimental materials and tools. Students explored how to develop electrochemical cell and electrolysis cell by following experiment instruction with related figures to guide them in conducting the experiments (Figure 2b). This phase is known as the exploration phase. Design and experiments phase is when students design the experiment setup according to the instruction given and modify it to perform different test for the experiment. Students identified the processes that occur along with the experiments as well as learning about anode and cathode. The module also provided the experimental datasheet to let the students record the experimental result (Figure 2c).

Questions from different levels of Bloom's Taxonomy (C1 to C3) were created in the module to strengthen student understanding of the topic (Figure 2d). The answers were also provided in the module to familiarise students with the correct way of writing the formula, half-cell equation and overall equation related to the experiment. This is called reflection phase. Malay language, which is the national language in Malaysia, was chosen as the writing language in this module.

(a)

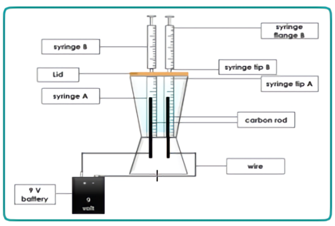
(b)

1. Prepare 250 ml salt water 0.5 M.

Please refer page 56 for calculation of table salt mass needed.

2. Pour the table salt into the plastic cup until full.
3. Carefully covered the carbon rod with syringe A and close the plastic cup with the lid. Make sure syringe tip A is inside the provided hole in the lid.
4. Connect syringe B at the top of syringe A using rubber tube as in Figure 1.
5. Connect crocodile clip at both ends of carbon electrode and terminal battery.

Figure 1 Electrolysis set of LECTROFUN 2.0



(c)

RESULT AND DATA TABLE

1. Determine the material used as anode and cathode for electrolysis cell in Figure 1.

Anode:	
Cathode:	

2. From your observation, what is happening on anode and cathode?

Table 1 Observation of reaction in electrolysis cell

Electrolyte Concentration	Observation	
	Anode	Cathode
0.5 M		
5.0 M		

(d)

3. Write down the half cell equations for electrolysis cell in Figure 1.

Table 2 Half cell equations of electrolysis cell

Electrode	Concentration	Half cell equations
Anode	0.5 M	
	5.0 M	
Cathode	0.5 M	
	5.0 M	

4. Write down 2 full cell equations for electrolysis cell in Figure 1 in both low and high concentrations.
5. State the changes of energy in the electrolysis process.
6. Explain the relationship between electrolyte concentration and selection of discharge ion at anode.
7. What is the function of food colouring in this experiment?
8. What is the gas produced at anode and cathode?

Figure 2. (a) Lectrofun 2.0 Module, (b) Procedure of Experiment, (c) Datasheet of the Experiment and (d) Variety of Questions Provided

Lectrofun 2.0 (kit and module) and pre-post tests were validated by three experts in a university in Malaysia. Pre-post tests were built based on concepts delivered in the Lectrofun 2.0 Module. Pre and post-tests had the same 27 questions, but the questions were arranged in a different sequence. The questions are on electrolysis cell, Galvanic cell, writing of half-cell equations, writing of full cell equations, experimental observation results, and factors influencing ion selection at anode and cathode. Content Validity Index (CVI) of the Lectrofun 2.0 and pre-post tests are 0.93 and 0.94, respectively.

The module was implemented in the pilot test to obtain the reliability value. Pilot study was carried out with a group of students in a secondary school in Perak. The Cronbach's alpha value (0.77) was generated using Statistical Packages for the Social Sciences (SPSS) software version 23.

One instrument was used in this study to gather the data and information needed, which is a set of pre-test and post-test questions. The data were analysed using t-test method and percentage score of student achievement. Total of 46 students were involved in the case study to investigate the effectiveness of Lectrofun 2.0. Form 4 students (age 16) who took chemistry subject in a secondary school in Malaysia were the population of this study. Sample was selected using a cluster random sampling method. The sample was divided into two groups: the control group (23 students) and the treatment group (23 students).

The research was conducted during the academic session of June to December semester. Pre-test and post-test were scheduled on different days as the post-test was given at the end of teaching and learning of electrochemistry session. Table 1 refers to the duration of the research process.

Table 1. Duration of the Research Process

Sample	Observation	Experimental (3 weeks)	Observation
Treatment group: 23 students	Pre-test (75 min)	Used Lectrofun 2.0 in teaching electrochemistry topic	Post-test (75 min)
Control group: 23 students	Pre-test (75 min)	Used conven-tional method in teaching electrochemistry topic	Post-test (75 min)

Both groups' prior knowledge in electrochemistry topic was tested with a pre-test. Students were given 75 minutes to answer the pre-test before the teaching and learning of electrochemistry topic. Treatment group was taught using Lectrofun 2.0 experimental kit in combination with the guided inquiry method. Control group was taught using conventional method according to the specified form 4 chemistry syllabus. Control group students were also required to prepare conventional electrochemistry experiments. Post-test was given to examine their comprehension throughout the class after both groups had finished learning electrochemistry topic in three weeks.

The students' achievement scores from both pre-test and post-test were put in grading scale as shown in Table 2. Students' performance in achievement test was categorised into five (5) different grades based on score range shown in Table 2. This grading scale and grading status were used by Malaysia government schools based on the School Examination Analysis Computer System (SAPS) developed by the Ministry of Education Malaysia (MOE).

Table 2. Grading Scale for Achievement Test

Score	Grade	Status
80-100	A	Distinction
65-79	B	Credit
50-64	C	Pass
40-49	D	Pass
0-39	E	Fail

The result of pre-post tests for control group (N = 23) and treatment group (N = 23) were analysed to test the hypotheses. The four research hypotheses (Chua, 2006) are:

H_{01}: There is no significant difference in the pre-test scores between control and treatment groups.

H_{02}: There is no significant difference between pre-test and post test scores in control group.

H_{03}: There is no significant difference between pre-test and post test scores in treatment group.

H_{04}: There is no significant difference in the post test scores between control and treatment groups.

The data obtained were analysed with descriptive analysis and inference analysis. An independent sample t-test (H_{01} and H_{04}) and paired sample t-test (H_{02} and H_{03}) were conducted to test the hypotheses.

RESULTS AND DISCUSSION

Evaluation phase in ADDIE model is discussed in detail in this section. The results of pre-test mean scores for control and treatment groups are shown in Table 3.

Table 3. Pre-test Mean Scores for Control and Treatment Groups

G	N	M	SD	t-value	Significance
C	23	10.57	8.57	-1.109	0.273
T	23	13.61	9.99		

*Indicator: G(Group), C(Control), T(Treatment)

Null hypothesis (H_{01}) failed to be rejected because there was no significant differences in the pre-test scores between control group (M = 10.57, SD = 8.57) and treatment group [M = 13.61, SD = 9.99; t(44) = -1.109, p = 0.273] where p-value was greater than 0.05. The result indicates students from control and treatment groups have equivalent prior knowledge in electrochemistry topic because students were not exposed to electrochemistry concepts in their early education.

Table 4. Control Group's Mean Scores for Pre-test and Post-test

G	N	M	SD	t-value	Significance
Pre-test	23	10.57	8.57	-7.108	0.00
Post-test	23	32.61	16.10		

From the result in Table 4, we can conclude that null hypothesis (H_{02}) was rejected because there was a significant difference in the pre-test (M = 10.57, SD = 8.57) and post-test [M = 32.61, SD = 16.10; t(22)= -7.108, p = 0.00], where p value was less than 0.05. This indicated that students from control group have acquired a certain level of knowledge in electrochemistry topic after three weeks of learning and teaching session.

Table 5. Treatment Group's Mean Scores for Pre-test and Post-test

G	N	M	SD	t-value	Significance
Pre-test	23	13.61	9.99	-46.37	0.00
Post-test	23	85.89	9.18		

From the result in Table 5, null hypothesis (H_{03}) was rejected because there was significant differences between pre-test (M = 13.61, SD = 9.99) and post-test [M = 85.89, SD = 9.18; t(22) = -46.37, p = 0.00] where p-value was less than 0.05. This proved that the treatment group had good comprehension of electrochemistry topic after three weeks of learning and teaching session using Lectrofun 2.0. Green experimental-based learning is an instructional strategy that utilises natural sources as a teaching tool. It encompasses experimental procedures, data sheets, and reflective questions. Utilisation of recyclable materials and familiar materials by students in the experimental setup is one way of providing students with a creative learning environment. Students will not be overwhelmed by learning through textbooks in schools and this encourages students to develop their creative skills. (Davies et al., 2013). They could reconstruct their experimental materials using different types of fruits and vegetables in a galvanic cell setup. They could also switch electrodes provided in other metal materials in the galvanic cell setup and observe the changes. This process allows students to gather information regarding the materials they are interested in and to engage in discussions based on their existing knowledge and background, thus encouraging them to explore and innovate to develop their creative thinking ability.

Table 6. Post-test Mean Scores for Control and Treatment Groups

G	N	M	SD	t-value	Significance
C	23	32.61	16.10	-13.79	0.00
T	23	85.89	9.18		

*Indicator: G(Group), C(Control), T(Treatment)

From the result in Table 6, the null hypothesis (H_{04}) was rejected because there was significant difference in post-test mean scores between control group (M = 32.61, SD = 16.10) and treatment group [M = 85.89, SD = 9.18; t(44) = -13.79, p = 0.00] where p-value was less than 0.05. This indicated that students from control and treatment groups have different levels of understanding toward electrochemistry topic.

After participating in the activities presented in this study, the treatment group showed significant improvements with regard to their knowledge about electrochemistry concept. They were capable of identifying the anodes and cathodes for electrolysis cell and galvanic cell, determine the reactions that occur in the anode and cathode, analyse the differences in electrolysis cell and galvanic cell, and they could relate electrochemistry concept to the real world. This is proven by the score percentage data for each question in pre-post test in the treatment group (Table 8).

Although both control and treatment groups undergo electrochemistry experiments, the conventional setup has a weakness in collecting gas, thus disrupting the learning process among students (Everett, 2017). Students found it was difficult to collect gas from an electrode using an inverted test tube filled with solution. In addition, no electrolysis cell experiment on high electrolyte concentration was performed due to students' safety concern against a high concentration of chemical that could pose a greater risk of harm. Therefore, students cannot see the process practically and eventually they have to memorise the theory taught in the classroom. This hinders the learning process. Effective learning requires people to learn through hearing, seeing, and doing. Some 80-90% of people generally remember what they hear, see, and do (Kolb, 1984).

Failure to perform the experiment was evidenced by the decrease in the percentage score, as shown for question 2a and 2b in Table 9.

In contrast, the treatment group has successfully collected the gas generated from the electrolysis process and the gas test experience runs smoothly. Satisfaction and excitement in successfully conducting correct and proper experiments help students to recall and reflect on what has happened (Lo, 2010). The use of green chemistry applied in the green electrochemistry kit helps students feel more confident in conducting experiments without worrying about the danger of chemicals (Collins, 2017). This can help in increasing the smooth understanding of electrochemical concept. Students are more focused on finding concepts and more active in learning when given suitable learning material (Riley & Jones, 2010; Jannah et al., 2013).

The result for comparison of participant performance between treatment group and control group is shown in Table 7.

Table 7. Comparison of Participants' Performance between Treatment Group and Control Group

		Treatment group		Control group	
Score	**Status**	**Pre-test**	**Post-test**	**Pre-test**	**Post-test**
80-100	Distinct	0 (0.0%)	17 (73.9%)	0 (0.0%)	0 (0.0%)
65-79	Credit	0 (0.0%)	6 (26.1%)	0 (0.0%)	0 (0.0%)
50-64	Pass	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (13.1%)
40-49	Pass	1 (4.3%)	0 (0.0%)	0 (0.0%)	4 (17.4%)
0-39	Fail	22 (95.7%)	0 (0.0%)	23 (100.0%)	16 (69.57%)

In the pre-test, no participant from treatment group, nor the control group obtained grade A, B or C (distinction, credit or pass). Moreover, only one participant (4.3%) from treatment group scored grade D (pass) in pre-test, and 22 participants (95.7%) from treatment group get grade E (fail). In contrast, 23 participants (100.0%) from control group fail the pre-test. This performance is in line with the *t*-test value in Table 3. At the beginning of the study, the knowledge of electrochemistry among the sixteen-year-old students in both groups was generally poor. Most of the electrochemistry concepts and new chemistry terms were unfamiliar to them. They were unable to relate the electrochemistry concepts with their existing knowledge and experiences. This can cause misconceptions among the students. Finding of Bong and Lee (2016) showed that secondary students' misconceptions were caused by lack of basic knowledge, language obstacles and applying rote learning in studying electrochemistry.

Both groups showed improvement in the post-test. It is supported by t-test result in Table 4 and Table 5. A total of 17 students (73.9%) from treatment group succeeded in achieving grade A (distinction) in the post-test from grade D and E in the pre-test. While in the control group, seven students have two-grade (grade C and D) improvement from grade E in the pre-test. This data is in line with t-test result in Table 6. It is proven that Lectrofun 2.0 is a useful teaching and learning aid for improving student achievement in electrochemistry test. Thus, it gives a positive impact on students in learning electrochemistry.

The scoring percentage for each question between the pre-post test in both treatment and control groups is shown in Table 8 and Table 9.

Table 8. Score Percentage for Each Question between Pre-Post Test in Treatment Group

Questions	Pre-test Percentage	Post-test Percentage	Percentage Difference
1a	52.17	80.43	28.26
1b	13.04	39.13	26.09
2a	43.48	65.22	21.74
2b	13.04	43.48	30.43
2c	43.48	67.39	23.91
2d	30.43	82.61	52.17
2e	13.04	73.91	60.87
3	43.48	86.96	43.48
4	52.17	95.65	43.48
5	39.13	47.82	8.70
6a	15.22	70.65	55.43
6b	7.41	65.22	57.81
6c	34.78	85.87	51.07
6d	17.39	91.30	73.91
7a	28.26	86.96	58.70
7b	8.70	84.78	76.09
7c	4.35	39.13	34.78
7d	15.22	44.79	29.57
8a	39.13	100.00	60.87
8b	0.00	34.78	34.78
8c	21.74	82.61	60.87
9	0.00	95.22	95.22
10	0.00	94.57	94.56
11	6.52	97.83	91.30
12	0.00	61.96	61.96
13	0.00	92.03	92.03
14	5.26	97.71	92.45

From Table 8, question 8(a) score percentage is 100% in post-test. This indicates all students in treatment group had memorised the factors influencing ion selection in electrodes. Question 9 (95.22%), question 10 (94.57%), question 13 (92.03%), question 14 (92.45%) and question 11 (91.30%) in post-test were also among questions recording the highest increment. The questions are about drawing and labelling electrolysis cell and galvanic cell diagrams (question 9), state six differences between electrolysis cell and galvanic cell (question 10), examples of real-life application in electrolysis cell and galvanic cell (question 13), position of anions and cations in electrochemical series (question 14) and the definition of anode and cathode and how to determine anode and cathode in electrolysis cell and galvanic cell (question 11). The data show the treatment group students have a clear idea of difference between the diagram and the characteristics of electrolysis cell and galvanic cell. They understand the position of anions and cations in the electrochemical series, and they could relate application of both cells in real life.

Table 9. Score Percentage for Each Question between Pre-Post Test in Control Group

Question	Pre-test Percentage	Post-test Percentage	Percentage Differences
1a	34.36	39.06	4.69
1b	9.38	15.63	6.25
2a	23.44	21.88	-1.56
2b	15.63	12.50	-3.13
2c	42.19	45.31	3.13
2d	34.38	37.50	3.13
2e	1.56	12.50	10.94
3	40.63	46.88	6.25
4	46.86	59.38	12.50
5	0.00	18.75	18.75
6a	17.39	34.78	17.39
6b	3.13	9.38	6.25
6c	22.40	37.24	14.84
6d	0.00	28.13	28.13
7a	21.88	43.75	21.88
7b	0.00	21.88	21.88
7c	0.00	4.69	4.69
7d	21.88	43.75	21.88
8a	24.64	68.11	43.48
8b	0.00	4.35	4.35
8c	9.38	21.88	12.50
9	0.94	40.00	39.06
10	0.00	7.03	7.03
11	0.00	5.47	5.47
12	0.00	0.00	0.00
13	1.04	13.54	12.50
14	10.69	72.20	61.51

Table 9 compares score percentage for each question between pre-post test in the control group. Based on Table 9, question 14 in post-test had the highest percentage difference of 61.51%. Electrochemical series is a series of chemical elements arranged in order of their standard electrode potentials and was recalled well by the control group. The score percentage decrease, in contrast, occurred in question 2a (-1.56%) and question 2b (-3.13%). These pertain to the writing of half-cell equations and full cell equations to process electrolysis cell at high electrolyte concentration.

The data show that control group students only understand simple theoretical information at level C1 and C2 of Bloom's Taxonomy. The decrease in score percentage indicates that students were impotent in applying questions at level C3 of Bloom's Taxonomy, although having had three weeks of lessons. This proves that there is still imperfection in the conventional electrochemistry experiments at school that needs attention. The impairment has been successfully overcome by Lectrofun 2.0, as evidenced by the treatment group achievement in questions 2a, 2b, 8a, 9, 10, 11, 13 and 14.

CONCLUSION

Lectrofun 2.0 was successfully developed using green chemical, recyclable, and easily accessible materials. It had Content Validity Index (CVI) of 0.93, and reliability value 0.77. Lectrofun 2.0 enables students to integrate daily life materials into the experiment. This study showed that Lectrofun 2.0 increased students' scores in electrochemistry in the achievement test. About 73.9% of students in the treatment group showed four grade increments (from grade E to grade A) in post-test scores. This shows that Lectrofun 2.0 has a significant impact on enhancing learner comprehension of electrochemistry topic by creating a fun and enjoyable learning environment.

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