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Development of a Do-It-Yourself (D.I.Y.) Gel Electrophoresis Apparatus for Grade-12 STEM General Biology Students

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Abstract. A hurdle to effective science education in schools is often the lack of teaching materials. Teaching science education in the 21st century requires direct visualization and manipulation with effective use and implementation for meaningful learning to occur, thus, unleashing students' potential towards the lesson, boosting their engagement in learning, and applying the knowledge into skills. This study was carried out to develop a do-it-yourself gel electrophoresis apparatus. This study was conducted in Cebu Normal University, Philippines with nineteen (19) teachers from the Methods of Teaching Science and Instructional Trends and Issues Class who evaluated the apparatus in terms of usability and functionality. The respondents tested the Gel Electrophoresis apparatus by conducting the experiment and they evaluated the apparatus' functionality and usability by using an evaluation sheet which is composed of eleven (11) usability questions, four (4) functionality questions. Suggestions were also asked to improve the said apparatus. After gathering data, the suggestions made by the respondents were incorporated which resulted to the improved D.I.Y. Gel Electrophoresis Apparatus. A manual with the procedures was also designed to further guide students and teachers on how to build the apparatus. With the findings and results obtained in the study, the respondents recommended the usage of the developed do-it-yourself gel electrophoresis apparatus in their respective classes and agreed that it is a good source of learning the concept of gel electrophoresis as a 21st century biological technique. The apparatus was easy to set-up and is of low-cost. During experimentation, the apparatus yielded with a positive result – the separation of food dyes which follows the principle of gel electrophoresis. Moreover, the experiment encourages creativity and it helps with the understanding of the nature of DNA and the concept of gel electrophoresis as a 21st century biological skills.

1. Introduction

Science education at all levels of schooling is often seen as abstract and irrelevant to life. Students in mathematics and physics feel that their discipline contents are abstract and cannot apply these materials to the real world and students in biology and chemistry, on the other hand, are loaded with memorization of facts. In general, students fail to see that science is all around them, and the best way to view the different aspects of their lives it through scientific method [7]. With the rapid technological change, a lot of factual information is available on the internet, and artificial intelligence is making certain occupations obsolete. Therefore, it is significant to instill to students the fundamentals that will stay with them for the rest of their lives. These essential tools include language skills such as comprehension, communication, and expression, as well as quantitative skills such as identifying variables, seeing hidden patterns, analysis, and generate solutions to problems.

The purpose of science education should not just be training scientists but introducing students to a scientific way of thinking that will make them better citizens. As stated further, science education benefits not only the individual but society as a whole. The inability of common people to understand and interpret graphs, statistics, and scientific data could threaten democracy because in a democratic country, the collective views and skills of citizens influence and affect the nation's directions [7].

Effective science education experiments could not be realized due to the lack of teaching materials. Thus the concept of improvisation has become increasingly a trend in the discourse of scientific experiments. Through this, an actual application of the theoretical knowledge will be realized and will help the demonstration of the psychomotor skills of the students and teachers who performed the experiments [3].

A study led by the University of Chicago proved that experiments help kids learn scientific concepts [5]. It was seen in brain scans that the involvement of a student in hands-on activities activated the sensory and motor-related parts of the brain. These students were said to perform better in tests. Letting students kinesthetically and visually learn would definitely help them understand science concepts better. By exposing students to how gel electrophoresis works through experiments, a deeper knowledge about this topic will be acquired. They will not only "hear" about the said topic in class discussions, but also see how it works and what results it may give. In addition to that, they will be able to personally experience and do the whole process themselves. Aside from experiments being an effective way to teach concepts, it can also provide or improve vital skills.

The development of problem-solving and critical thinking skills are two of the benefits students can get through laboratory experiments [1]. In this setting, students try to think and understand how their results have come into place. These skills are beneficial in one's life. Honing the students' knowledge in science while helping them grow into critical thinkers should be a good reason to start introducing biological techniques to students through experiments. Schools do not only exist to help students academically. It's also there for one's growth as a person who will go through life.

Critical thinking aids a person in coming to a decision. It helps one rationalize, and judge situations that may or may not be favorable to the person [6]. Through critical thinking, students may be able to identify the cause of the problems that may arise during the experiment. Once the problem is already known, students will try to solve these to complete the whole process. Science experiments and hands-on activities encourage students to think, and be diligent in searching for answers.

2. Theoretical Background

The research is based on Piaget's theory of Constructivism. In this theory, it states that knowledge is built upon the past experiences and learnings [4]. If someone is exposed to a new situation that requires problem solving, this person uses his experiences to direct the problem. From there, these learnings will be incorporated, and will be used to arrive at a conclusion. The theory of constructivism is usually applied in teaching through hands-on activities. It encourages students to reflect on their experiences, and apply it to the concept under discussion. It involves the students' own learnings without having to rely on others. After the activity, it is usually followed by a group discussion where the students share their ideas. The students may support their own thoughts by using their experiences as evidences.

In this study, a D.I.Y. gel electrophoresis is constructed that may be used by the students. This will allow the students to use their basic knowledge on the nature of macromolecules such as DNA and proteins they got from classroom discussions. This knowledge will be applied to a new setting which is the experiment on gel electrophoresis. Through this, they will construct their knowledge on the concept. Thus, a deeper understanding about gel electrophoresis will be achieved. Through the experiment, the students get to experience firsthand how the process works. This builds their knowledge about the concept.

The gel electrophoresis is a 21st century biological technique that separates, isolates, differentiate, study and analyze macromolecules like DNA and proteins [2]. The researchers created a do-it-yourself gel electrophoresis apparatus with the hopes to introduce the concept to students without it being costly. Original material were substituted to common household items or those that can be found in the locale.

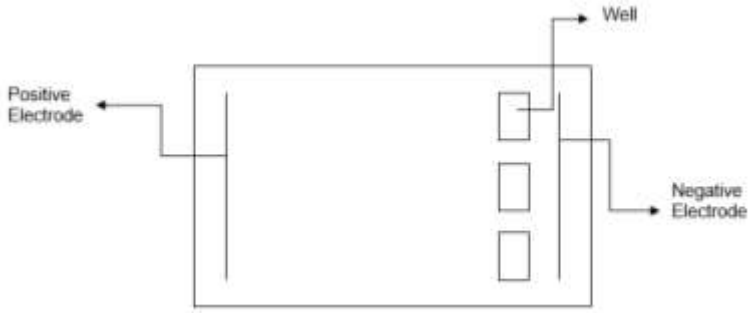

Figure 1. Schematic diagram of the gel electrophoresis apparatus

Figure 2. The developed do-it-yourself gel electrophoresis apparatus

The gel electrophoresis apparatus allows us to study the study of macromolecules such as DNA and proteins. It uses electricity to separate the molecules under study. The do-it-yourself apparatus introduces this concept to students with the use of common household materials. A small box made of insulator material is being used as the container of the gel where the whole process take place. Two (2) copper wires will be bent, and hooked at the edge of the box. These will serve as the negative and positive electrodes. After this step, a "comb" must be made using cardboard. It should be placed close to the negative electrode. This material will be used to make wells of the gel where the food dyes will be inserted. Next, the buffer solution is to be made by mixing three-fourth (3/4) teaspoon of baking soda and three-hundred (300) mL distilled water. The gel must also be prepared by adding three (3) teaspoons of gulaman powder to two-hundred (200) mL of the buffer solution that was made in the previous step. Bring this solution to a boil while continuously stirring. Once done, the solution will be poured in the box. This will soon settle as the temperature cools down. When the gel is ready, the copper wires must be placed inside the box at opposite ends, and the comb must be carefully removed from the gel. Then connect five (5) nine-volt batteries together; this will serve as the power source of the apparatus. Using alligator clips, connect the negative electrode to the negative end of the battery. Do this to the positive

side as well. Lastly, insert three different food dyes to the wells using a syringe. The process will then take place for fifteen (15) minutes or until the separation is already visible.

The expected result of this experiment is the separation of colors of the food dyes. Based on the principles of gel electrophoresis, this is due to the attraction of negatively charged molecules of the dyes to the positive electrode. Another principle is that lighter molecules migrate faster than heavier ones. Thus, the color to the negative electrode, as seen from the set-up, contains heavier molecules.

3. Methods

3.1 Target Group

The target respondents of the study were the nineteen (19) masteral students of Cebu Normal University, Cebu City Philippines who were enrolled in the Methods of Teaching Science and Instructional Trends and Issues Class of the 2nd semester of school year 2018-2019. These masteral students are teaching science in public and private high schools.

3.2 Methods of Inquiry

Research and Development (R&D) design was employed in the study where it aimed to evaluate the functionality and usability of the gel electrophoresis apparatus. The researchers searched ways on how to create a gel electrophoresis apparatus. Each part of the apparatus was also studied in terms of its purpose and properties. The researchers then altered some materials to things that are readily available in the locale. The apparatus was then constructed using the said materials that were altered. The researchers then tested the apparatus, and made changes along the way like the container, quantity of buffer solution, and concentration of gel. The main goal of this research is to test for the apparatus' usability and functionality. The researchers surveyed nineteen (19) graduate students from the "Methods of Teaching Science and Instructional Trends and Issues" class in Cebu Normal University, Cebu City, Philippines. They were asked to complete a survey-questionnaire after using the D.I.Y Gel Electrophoresis Apparatus. The survey-questionnaire followed a likert-scale format for the respondents to rate the functionality and usability of the apparatus. Moreover, open-ended questions were included to ask for the suggestions for the improvement of the apparatus.

After the evaluation of the apparatus, the gathered data was analyzed and the suggestions from the evaluators were incorporated. A manual was also designed as the final step of the development process for the purpose of guiding students and teachers on how to construct the apparatus and understand the principles of the gel electrophoresis.

4. Results and Discussion

Necessary modifications were made to the apparatus for the reasons of reducing running time of the experiment and for the convenience of other high schools. One modification was changing aluminum foil into galvanized iron wire wrapped in aluminum foil as this material is cheaper and easier to find. Another is modifying the concentration of one-half (½) teaspoon agar into three (3) teaspoons of gulaman powder into a two-hundred (200) mL buffer solution. This modification helps in reducing the running time for this experiment. Lastly, the use of bunsen burners and electric plate instead of microwave oven for the convenience of other high school laboratories with less facilities.

Increasing the quantity of gulaman powder into a two hundred (200) mL buffer solution reduces settling time. The researchers found out three (3) teaspoons of gulaman powder results into a settling time of nineteen (19) minutes. The researchers used this quantity as the final amount.

The materials used as electrode have been modified for various reasons. The electrode copper wire shows no reaction and no visible separation within fifteen (15) minutes of running time. Galvanized iron wire shows a separation of colors in food dyes, but has a presence of green solid that mixes with the buffer solution. As a solution, the researchers wrapped the galvanized iron wire with aluminum foil to prevent any formation of solids and shows separation of colors in food dyes.

Figure 3. Evaluation of the apparatus through experimentation

The table below shows the evaluators' rating on the usability of the developed do-it-yourself gel electrophoresis apparatus. There are two questions with the highest rating and had a mean of 3.47. The respondents strongly agreed that the experiment encouraged them to participate in class and the respondents strongly agreed that the experiment was a fun learning experience. The question with the lowest rating had a mean of 2.95. The respondents agreed that the experiment helped them understand the nature of DNA and more. Although this was the lowest, the rating still aligned to the positive side of the scale. Overall, the respondents rated the usability of the apparatus with an average mean of 3.27.

Table 1. Evaluators' Rating on the Usability of the D.I.Y. Gel Electrophoresis Apparatus.

Criteria	Mean	Description
1. The gel electrophoresis experiment was conducted well and was organized.	3.05	Agree
2. The procedure for the experiment was explained well in the procedure sheet that was distributed.	3.11	Agree
3. The experiment encouraged me to participate in class.	3.47	Strongly Agree
4. The experiment went well for our group.	3.11	Agree
5. I was happy that the apparatus was made from low-cost materials.	3.42	Strongly Agree
6. The experiment made me think creatively.	3.42	Strongly Agree
7. Using the gel electrophoresis apparatus made me gain more interest in science.	3.37	Strongly Agree
8. The experiment helped me understand the nature of DNA more.	2.95	Agree
9. I learned something from the experiment.	3.27	Strongly Agree
10. The experiment made me want to do more experiments.	3.37	Strongly Agree
11. The whole experiment is a fun learning experience.	3.47	Strongly Agree
Average	**3.27**	**Strongly Agree**

The functionality of the apparatus was rated by the respondents. The question with the highest rating had a mean of 3.26. The respondents strongly agreed that the electrodes were easy to place inside the gel. The question with the lowest rating had a mean of 2.68. The respondents agreed that the dyes ran from the negative electrode to the positive one. It was the lowest rating due to an inconsistent amount of food dye dropped into the wells. Although it had the lowest rating, it still belongs to the positive side of the scale. Overall, the respondents rated the functionality of the apparatus with an average mean of 3.07 as shown in Table 2.

Table 2. Evaluators' Rating on the Functionality of the D.I.Y. Gel Electrophoresis Apparatus.

Criteria	Mean	Description
1. It was easy to place the electrodes inside the gel.	3.26	Strongly Agree
2. There were no difficulties in putting the dyes inside the wells.	3.21	Agree
3. The dyes ran from the negative electrode to the positive one in our experiment.	2.68	Agree
4. It was easy to use the whole set-up in general.	3.11	Agree
Average	**3.07**	**Agree**

The respondents gave their opinion on why they would consider using the D.I.Y Gel Electrophoresis Apparatus in their class and the feedback was generally positive. The common reasons were: the apparatus is an economic experience that many can benefit from, and another is that this experiment deepens the understanding of the nature of DNA and more.

The respondents gave their opinion whether they would recommend the D.I.Y. Gel Electrophoresis Apparatus to other Science Teachers or not. 16 (sixteen) out of 19 (nineteen) respondents responded they would recommend this experiment whereas 3 (three) out of 19 (nineteen) respondents did not answer. The respondents reasons are: this experiment helps with the understanding the concept behind this, and this experiment further expands their knowledge on the nature of DNA and more.

The researchers asked for suggestions from the respondents to further improve the D.I.Y. Gel Electrophoresis Apparatus. One suggestion was the use of a different electrode. This suggestion was mentioned because during the experiment the electrode used was galvanized iron wire and as a result, there was a green precipitate present. As a solution, the researchers used galvanized iron wire wrapped in aluminium foil to prevent precipitates. Another suggestion mentioned was the measurement for the amount of dye and amount of buffer solution needed for the experiment. The specific measurements will be specified in the booklet with the procedures most especially with the amount of dye to be dropped to create more accurate results in the experiment.

5. Conclusion

With the findings and results obtained in the study, the respondents recommended the usage of the developed do-it-yourself gel electrophoresis apparatus in their respective classes and agreed that it is a good source of learning the concept of gel electrophoresis as a 21st century biological technique. The apparatus was easy to set-up and is of low-cost. During experimentation, the apparatus yielded with a positive result – the separation of food dyes which follows the principle of gel electrophoresis. Moreover, the experiment encourages creativity and it helps with the understanding of the nature of DNA and the concept of gel electrophoresis.

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