The Development of Piezo Electric Alcohol Rocket Launcher (PEARL) as an Educational Tool: Promoting Chemistry Literacy

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Abstract

Recent studies on educational tools have resulted in breakthroughs in students' interest and motivation. The aim of this study is to demonstrate the use of a developed educational tool (called P.E.A.R.L.) that enhances students' chemistry literacy. The research was conducted at SPK SMAK PENABUR KELAPA GADING, involving a total of 31 participants. A simple methodology was employed, constituting a quantitative study with a pretest and post-test structure. The test assessed participants' chemistry literacy, specifically focusing on their comprehension of thermochemistry concepts. It comprised four questions, evaluating both theoretical and analytical knowledge, referencing an article on the Beirut port explosion. Non-parametric tests were used for data analysis, revealing a significant increase in the average achievement of the students. This suggests a notable improvement in students' chemistry literacy, with a Wilcoxon Rank Test p-value < 0.001 at $\alpha=0.05$. The rank biserial correlation value of 0.807 indicated a positive correlation in the data, falling within the 'large' effect size. The steps to build the Piezo Electric Alcohol Rocket Launcher (P.E.A.R.L.) were published on the Autodesk Instructables website.

Keywords: Educational Tool, Chemistry Literacy, PEARL, STEM, Thermochemistry

Introduction

Chemical explosions can lead to significant calamities and result in numerous civilian casualties. The explosion in Beirut on August 4, 2020, resulted in a colossal blast, creating a 140-meter-wide crater and causing an earthquake measuring 3.3 on the Richter scale. The immediate consequences were devastating, with almost 220 people losing their lives and over 6,500 individuals sustaining injuries [1]. Additionally, approximately 300,000 people were left homeless. The negligence of storing approximately 2,750 tons of ammonium nitrate has led to this tragic incident [2]. This serves as a somber reminder of the critical importance of having a comprehensive understanding of chemistry literacy in our daily lives, especially in the decision making situation.

Chemistry education explicitly integrates energy-related topics, making scientific literacy in energy resources and environmental science a learning goal. However, nowadays, chemistry is still considered a hard science, known for its complexity and abstraction [3]. It poses a pivotal challenge in the pursuit to promote chemistry literacy. Chemistry literacy, by definition, is the ability to comprehend and apply chemistry knowledge effectively in daily life.

Moreover, the goal of chemistry education is to assist students in pursuing careers in science and technology. However, it faces challenges in its implementations such as a lack of transferable skills among graduates, the necessity for scientifically literate citizens, and a waning interest among young people in science and engineering [4]. International trends in chemistry education reveal that students find it challenging to grasp chemistry concepts and perceive them as non-essential [5]. It is evident that the lack of chemistry literacy contributes to lack of safety precautions and hazards as chemistry literacy explains the awareness in addressing such issues [6]. Therefore, it is imperative to enhance chemistry literacy among the next generation.

In recent research, there is still room for improvement in students' chemistry literacy. The use of educational games or tools has been shown to influence students' academic achievements, critical thinking abilities, knowledge, learning efficiency, and student attitudes [7]. In another study, a discussion platform for concepts through real-life experiences has a significant role in increasing students' chemical literacy levels. This study was conducted with 118 high school students. According to the findings, when the lesson design aligns with student interests, ensures the relevance of chemistry to students' lives, and integrates inquiry-based content understanding with inquiry as a support for learning, students' literacy skills may improve [8].

Based on these findings, there is a keen interest in developing an educational tool to elevate students' chemistry literacy. Therefore, the aim of the research is to develop an educational tool and use it to promote chemistry literacy. The research seeks to answer the following questions:

- Are the chemistry literacy scores normally distributed?
- Is there a notable increase in chemistry literacy scores after the assistance of an educational tool, P.E.A.R.L.?
- What is the effect size value of the treatment?

Literature Review

1. Chemistry Literacy

The foundation of chemistry literacy lies within science literacy, which involves the capacity to comprehend, communicate, and apply scientific skills to address societal issues. Scientific literacy, as per the definition provided by PISA (Program for International Student Assessment), encompasses the ability to apply scientific knowledge, recognize problems, describe scientific phenomena, draw conclusions based on evidence, and engage with scientific concepts and subjects [9]. This form of literacy translates scientific concepts into practical applications.

Yael Shwartz (2005) emphasizes that chemistry literacy involves understanding chemical ideas in four domains: contextual aspects, cognitive aspects, and affective aspects [10]. Hence, individuals lacking chemistry literacy may find it challenging to contribute to a society that values scientific literacy. A chemically literate individual comprehends the key concepts in chemistry, recognizing it as an experimental discipline that explores energy changes during chemical reactions. Chemists utilize a specialized language, and a chemically literate person applies their understanding of chemistry in daily life, making informed decisions as consumers of new products and technologies.

2. Piezoelectricity

The piezoelectric effect, also referred to as piezoelectricity, involves two essential processes within crystals: the generation of electricity through pressure and the creation of electric strain through electric fields. Lead zirconate titanate crystals ($Pb[Zr_xTi_{1-x}]O_3$), commonly known as PZT, are widely used as piezoelectric materials. Developed around 1952 at the Tokyo Institute of Technology, PZT is a chemical compound consisting of lead, zirconium, and titanate, synthesized at extremely high temperatures [11].

PZTs are applied in various devices, including gas lighters and medical imaging instruments (USG). In gas lighters, they operate by leveraging the piezoelectric effect to convert mechanical stress into electric signals. Gas lighters are equipped with a piezoelectric crystal (PZT crystal) embedded at one end of a spring, with the other end connected to a wired hammer. When the lighter is pressed, the hammer strikes the piezoelectric crystal, resulting in a high-voltage discharge in the space between two metallic points on the lighting end. This discharge ionizes the air in the small gap, creating a path for electric discharge that ignites the combustible gas [12].

Methodology

1. Research Goal

The aim of this study was to investigate the impact of implementing an educational tool into chemistry lessons and experiments on chemistry literacy.

2. Time and Location

This investigation took place at SPK SMAK PENABUR KELAPA GADING during both regular and after-school hours.

3. Data Resources

A pre- and post-test, comprising four questions under the topic of thermochemistry, was administered to 11th and 12th-grade participants. The test results served as the primary data for the research. Participants, aged between 17 and 18, provided individual consent to participate in the research. The pre- and post-test questions were taken from the RSC Education of a featured article by Nina Notman and Nora Richardson [13].

4. Research Methods to Build P.E.A.R.L.

To develop the educational tool, a simplified version of Borg and Gall's R&D method was employed. Initial data gathering and model planning were based on preliminary research findings. Additional data were collected to facilitate successful tool development. A prototype of the educational instrument was then created and verified by experts. The prototype underwent testing for functionality and adjustments were made as necessary. The final prototype underwent a field test, and the steps to build the product (P.E.A.R.L.) [14] were made available at https://www.instructables.com/Piezo-Electric-Alcohol-Rocket-Launcher-PEARL/.

5. Data Collection Techniques

A pre-experimental research design, including pre-test and post-test assessments, was employed to evaluate the chemistry literacy of SPK SMAK Penabur Kelapa Gading students. This approach was chosen due to the inability to have a control group for intervention evaluation. Data were collected through Google Forms, where participants answered thermochemistry-related questions. Chemistry literacy, representing participants' understanding and knowledge, was assessed. An informed consent letter was provided to each participant before the tests. The pre-test involved participants answering thermochemistry problems without exposure to educational tools. After building P.E.A.R.L. and applying thermochemistry principles through trial-and-error, participants were asked to answer thermochemistry problems again. Pre-test and post-test scores were collected two weeks apart.

6. Data Analysis Procedure

Google Forms data were analyzed based on participants' responses to each question. Four questions, encompassing theoretical and calculation-based aspects [13]. The method participants used to answer these questions was assessed, and their chemistry literacy percentage on the topic (thermochemistry) was determined. Wilcoxon Rank was employed to compare pre- and post-test results. Statistical tests were conducted using Jamovi version 2.3.21.

Results and Discussion

In the development of the educational tool (P.E.A.R.L.), PZT crystals function as the igniter, with the gas lighter serving as a trigger for the tool. A spark generated between a safely distanced wire at the pipe's end ignites the alcohol, producing enough pressure to propel the bottle ($C_2H_5OH + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$) [14]. The hot gasses from the combustion propels the bottles. The participants were able to conduct the various experiments with P.E.A.R.L. The effect of using the educational tool as a learning medium was reflected in the comparison between pre- and post-tests.

Table 1 is presented as descriptive statistics to evaluate the contribution of using the P.E.A.R.L. to students' chemistry literacy. The pre- and post-tests were conducted two weeks apart. In both the pre- and post-tests, participants were given an article about the explosion that occurred in Beirut's port, followed by four questions. Throughout the two weeks, participants were allowed to use the tool freely under adult supervision.

Table 1. Descriptive Statistics & Normality test

Statistical Parameters	Pre-test Score	Post-test Score
N	31	31
Mean	50.0	69.7
Median	40	80
Standard deviation	21.3	21.1
Shapiro-Wilk p	0.049	0.010

In Table 1, the pre-test mean score is 50.0, while the post-test mean is 69.7, with almost similar standard deviations. However, the mean and median scores are arguably not close to each other. This discrepancy suggests a deviation from normally distributed data in the pre- and post-test scores. In this case, the Shapiro-Wilk test at a significance level of 5% reveals that both the pre- and post-test p-values are 0.049 and 0.010, respectively. A p-value less than 0.05 is interpreted as a significant deviation from normal distribution, implying that the data are not normally distributed. This addresses the first research question, confirming that the data are not normally distributed [15]. Consequently, non-parametric statistics were employed for further data analysis.

Table 2. Wilcoxon Rank Test & Rank Biserial Correlation

			Statistic	p		Effect Size
Post-test Score	Pre-test Score	Wilcoxon W	342 [a]	< .001	Rank biserial correlation	0.807

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} > 0$

[a] 4 pair(s) of values were tied

Table 2 displays the results obtained from non-parametric tests conducted using Jamovi software. The Wilcoxon rank-sum test was employed to compare the pre- and post-test results. The null hypothesis was rejected as the p-value was less than alpha (0.05). It became evident that the post-test scores for chemistry literacy significantly increased compared to the pre-test scores. Therefore, the use of P.E.A.R.L. as an educational tool was found to be effective. This is further supported by the rank biserial correlation result of 0.807 in Table 2, indicating a large effect size [16] resulting from the intervention using the educational tool.

These findings align with previous research, indicating that learning innovations significantly enhance higher-order thinking and scientific literacy [17]. Some students expressed interest in integrating Arduino sensors with P.E.A.R.L. to measure the evolved heat. Arduino boards have been reported to foster creative thinking and problem-solving skills [18]. The learning activities involving P.E.A.R.L. contributed to the enhancement of thermochemistry skills, serving as a valuable learning medium for thermochemistry and its relevance to the study of the explosion phenomenon. Overall, participants' responses in the post-test demonstrated an improvement in their chemistry literacy, along with the use of a richer chemical vocabulary when answering questions. According to the post-test results, many participants correctly answered calculation questions, indicating an increased understanding of how chemical formulas are applied, the thermochemistry concepts involved, and calculations related to the enthalpy change of combustion.

Conclusion

In conclusion, the results of this study affirm that the use of the educational tool has significantly impacted students' chemistry literacy, leading to an increase. Substantial improvement was observed in students' declarations of knowing and understanding the chemical concept (thermochemistry) employed in the experiments with P.E.A.R.L. As demonstrated by the comparison of scores between pre-tests and post-tests in this study, students' chemistry literacy skills were significantly enhanced. The improvement was corroborated by a Wilcoxon Rank Test p-value < 0.001 at $\alpha=0.05$, and the rank biserial correlation value of 0.807 indicated a positive correlation in the data, falling within the 'large' effect size. Based on the findings of this study, we can assert that the use of the educational learning tool improves students' science literacy skills, specifically in understanding thermochemistry concepts. In the future, a more effective approach would involve providing more participants with longer exposure to the educational tool to have a stronger impact and increase the correlation value.

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