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Chemistry, the Central Science: The Application of a Multidisciplinary Project based on the Centrality of Chemistry

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Abstract Teaching chemistry to health sciences students using practical applications raises the concept of the centrality of chemistry, making the inter-relationships between one scientific branch and various other fields relevant. This multidisciplinary scientific project allowed health sciences students to apply different sciences to chemistry. Chemical, pharmaceutical, microbiological and statistical concepts were studied for the H_2O_2 reagent, in order to demonstrate that the scientific educational pedagogy is integrated for health sciences students.

Keywords Chemistry, Multidisciplinary, Chemometry, Scientific pedagogy

1. Introduction

Chemistry is often called the "Central Science", as it provides a significant degree of scientific branching, and connects the physical sciences [1-5]. This multidisciplinary project using H_2O_2integrates chemistry [6], pharmacology, microbiology, statistics and other sciences for health sciences students in support of the idea of the centrality of chemistry [7-8].

Hydrogen peroxide (H_2O_2) can be studied through many scientific branches related to chemistry [9]. For example, in pharmacology, H_2O_2 is a chemical reagent that has pharmacological and medicinal uses. H_2O_2 possesses bactericidal, sporicidal, fungicidal and virucidal antimicrobial qualities. It can therefore be used as an antiseptic to destroy or inhibit the growth of pathogenic microorganisms in non-sporing or vegetative states in medical environments. It can be used on living tissue as an antiseptic, or on inanimate objects as a disinfectant. Strong solutions of H_2O_2 (27–35%) are commonly diluted to prepare solutions for cleaning wounds and ulcers [10-11].

Microbiological pathogenic bacteria such as *Staphylococcus aureus* can be controlled by the application of H_2O_2. These bacteria can cause different types of diseases, from skin infections to endocarditis and toxic shock syndrome [12]. The main habitats of this bacterium are the nasal membrane and skin, usually considered the first line of defence against pathogens. If this bacterium enters the underlying tissues, the natural host's defence mechanisms are mediated by macrophages, which play an essential role by using toxic reactive oxygen species such as H_2O_2 to destroy the phagocytosed bacteria [13-15]. To avoid the toxicity of H_2O_2, *Staphylococcus aureus* can employa counter reaction, such as secreting the catalase enzyme, as this reacts with H_2O_2 to produce a safer form of O_2 gas. Despite the fact that *Staphylococcus aureus* responds this way in the catalase test, the toxic effect of H_2O_2 still persists [16].

Finally, statistics are important for chemists, especially in chemical analysis [17-24]. The use of statistical hypothesis tests can improve the selection of analytical methods used in analyses, based on significance tests. The application of mathematical and statistical methods to the designing and/or optimisation of measurement procedures and the providing of chemical information by analysing relevant dataraise the subject of chemometry [24]. Furthermore, the definition of statistics as a general concept is divided into two parts; the first concerns the collection, summarisation and analysis of the data, whereas the second only relates to drawing statistical inferences about a body of data when only a part of the data has been observed [17]. Statistical inferences can be drawn through the use of significance tests, and two such tests were employed in this project, the *f*-test and the *t*-test, and they are represented by the following mathematical equations:

$$f_{\exp} = \frac{s_A^2}{s_B^2} \quad (1)$$

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where S^2 is the variance.

$$t_{\text{exp}} = \frac{|\bar{x}_A - \bar{x}_B|}{\sqrt{\left(\frac{s_A^2}{n_A}\right) + \left(\frac{s_B^2}{n_B}\right)}} \quad (2)$$

where $\bar{x}$ and n are respectively the mean and the number of replications. The result of method (A) could be tested by comparing them with those of method (B). If the *f*- value calculated by equation 1 is larger than the critical value, then the null hypothesis that states $H_0 : s_A^2 = s_B^2$ is rejected, and the alternative hypothesis $H_A : s_A^2 \neq s_B^2$ is accepted. As a result, equation 2 is applied for the *t*-test. The significance of *t*-test is designed to determine type of the analytical error. If the null hypothesis $H_0 : \bar{x}_A = \bar{x}_B$ is retained, then the difference between two values can be explained by indeterminate error. The alternative hypothesis $H_A : \bar{x}_A \neq \bar{x}_B$ will rise if the null hypothesis is rejected, then the difference between the two values is great to be explained by indeterminate error [24].

2. Project methodology

Applications in various scientific fields are considered in this project: (1) Pharmacology, (2) Microbiology, (3) Nanotechnology, (4) Chemistry, (5) Statistics and (6) Computer Technology. The methodology and the student pedagogical objectives associated with each application are summarised in Table 1. This project is best suited for health sciences students. Diverse methodologies were used to achieve the project objectives, because scientific conclusions are generally drawn from both experimental and theoretical considerations. Chemistry is the central science among the aforementioned applications in Figure 1. Students are required to perform a laboratory experiment on a H_2O_2 redox titration to determine its H_2O_2 concentration. The results of five trials' reactions with $KMnO_4$ using a volumetric flask and an automated burette are analysed in a statistics and computer laboratory exercise, using Minitab software. The uses of H_2O_2, its effect on *Staphylococcus aureus* pathogens, particularly on the *Staphylococcus aureus* cell wall, are then discussed in terms of the relationships of pharmacology, microbiology and nanotechnology to chemistry. Laboratory experiments are essential in chemistry and statistics.

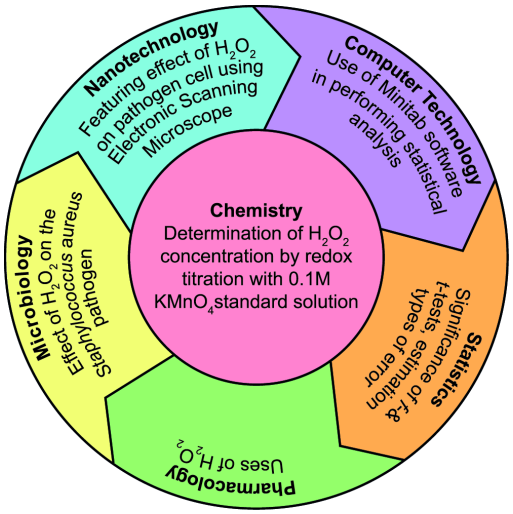

Figure 1. The project's interrelationships, and the relevance of multidisciplinary objectives, based on the centrality of chemistry

Table 1. Scientific fields considered in the project, and the corresponding scientometric methodology and pedagogical objectives

Scientific application	Methodology	Pedagogical objectives
Pharmacology	**Assignment:** Uses of oxidizing and reducing agents	Uses of H_2O_2
Microbiology	**Group discussion:** Formation of toxic ·OH radical by Fenton reaction	Effect of H_2O_2 on the *Staphylococcus aureus* pathogen
Nanotechnology	**Group discussion:** Analysis of ESM photos, highlighting their clarity compared to conventional glass slides	Featuring effect of H_2O_2 on pathogen cell using Electronic Scanning Microscopy (ESM)
Chemistry	**Experiment:** Redox titration of H_2O_2 by two methods (using a volumetric and an automated burette)	Determination of H_2O_2 concentration by redox titration with a 0.1 M $KMnO_4$ standard solution
Statistics	**Computer laboratory:** Introduction of chemometry and its importance in analytical chemistry	Significance of *f*- and *t*- tests, estimation and types of error
Computer technology	**Computer laboratory:** Data manipulation using Minitab software	Use of Minitab software in performing statistical analyses
Scientometric features	**Group Discussion:** Centrality of chemistry	Frequent encouragement of health sciences students to study chemistry and highlighting its relationship to their careers; teaching students to recognize the connections between their scientific courses to better understand their own specialization; the integration of both experimental and theoretical considerations into the scientific education pedagogy

3. Experimental

A classical redox titration was carried out to determine the concentration of an unknown solution (≈ 0.1 M) of H_2O_2. A total of 10.0 mL of this solution were pipetted into a conical flask and diluted with 200 mL water. Next, 20 mL of diluted sulphuric acid (1:5) was added and titrated with standard 0.1 M potassium permanganate ($KMnO_4$) to the first permanent, faint pink colour. The titration process was repeated at least five times. Finally, the final volume ofKMnO4was recorded.

$$2\ MnO_4^- + 5\ H_2O_2 + 6H^+ \longrightarrow 2Mn^{2+} + 5O_2 + 8H_2O \quad (3)$$

Our students employed redox titration (Eq.3) in the previously mentioned experiment using a volumetric burette (A) and an automated titrator (B) to fill the $KMnO_4$ solution. They collected the data by conducting the experiment independently and observing the results. The students summarised the data numerically by obtaining both the central tendency and the dispersion measures, as shown in Table 2, using the five readings of $KMnO_4$ volume in the *f*- and *t*-test with the aid of Minitab software [25].

Glass surfaces of the *Staphylococcus aureus* biofilm were prepared as previously described in the literature [26], and studied for the effect of H_2O_2 on the *Staphylococcus aureus* pathogen.

4. Hazards

Concentrated H_2O_2 is a corrosive and a reactive oxidizer; avoid contact with skin and inhaling its fumes. All workers in a microbiological laboratory that deals with *Staphylococcus aureus* must wear a protective coat and gloves, which should be removed before leaving the lab. Wash hands thoroughly after working with *Staphylococcus aureus*, mouth pipetting is forbidden, and hard surfaces such as benches should be cleaned and disinfected at the end of each working day. All *Staphylococcus aureus* cultures should be autoclaved at the end of the work to avoid contamination.

5. Results and Discussion

The pharmaceutical and medical uses of H_2O_2 (i.e., as a disinfectant and antiseptic) were explained to the students. Moreover, its microbiological effect on the *Staphylococcus aureus* pathogen was illustrated using ESM technology. Figure 2 shows the disruption of the *Staphylococcus aureus* outer membrane after H_2O_2 disinfection treatment, as seen by ESM.

The disruption of the outer membrane or the inhibition of *Staphylococcus aureus* activity can be explained by the reaction of H_2O_2 with the intracellular iron of the pathogen and the formation of the hydroxyl radical toxic form through the Fenton reaction:

$$Fe^{3+} + H_2O_2 \longrightarrow Fe^{2+} + \cdot OH + OH^- \quad (4)$$

The free radicals (·OH) in toxic form, attack essential cell components including lipids, proteins, and DNA. Sulfhydryl groups and double bonds are particularly targeted by (·OH), which increases the cell wall permeability by disrupting the mentioned bonds at the first defence attack (outer membrane) [14–15].

Table 2. Descriptive statistics for method (A) and method (B)

Method		**A Volumetricburette (mL) Graduation intervals (0.1)**	**B Automatedtitrator(mL) Graduation intervals (0.01)**
Trial			
1		6.8	4.50
2		6.9	4.30
3		4.4	4.30
4		4.5	4.50
5		4.3	4.40
Measures	**Type**		
Central Tendency	**Mean ($\bar{x}$)**	5.38	4.40
	Median	4.50	4.40
	Mode	No	4.3, 4.5
Dispersion	**Variance (s^2)**	1.807	0.01
	Standard Deviation (s)	1.344	0.10
	Coefficient of Variation(CV)	24.99	2.27
	Range ($\bar{\omega}$)	2.60	0.20

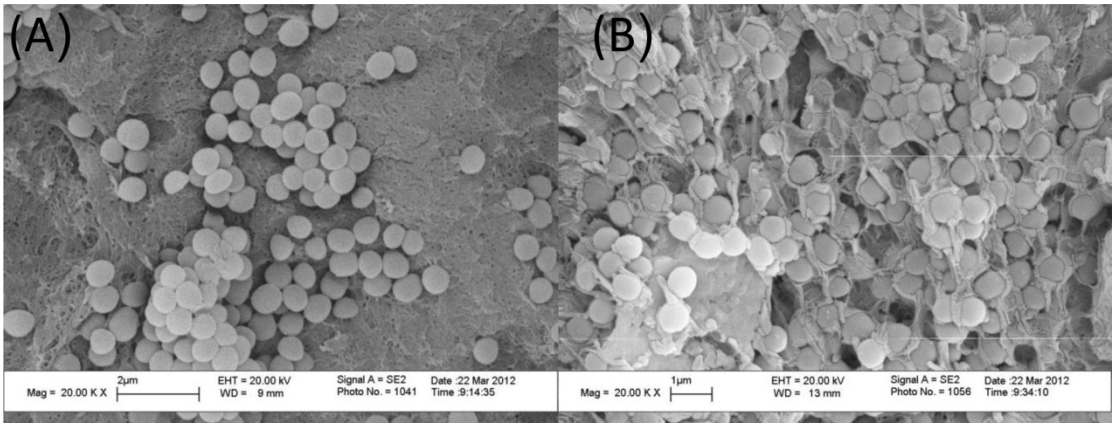

Figure 2. Disruption of the *Staphylococcus aureus* outer membrane by H_2O_2. The biofilm before (A) and after (B) H_2O_2 disinfection treatment, as seen by ESM

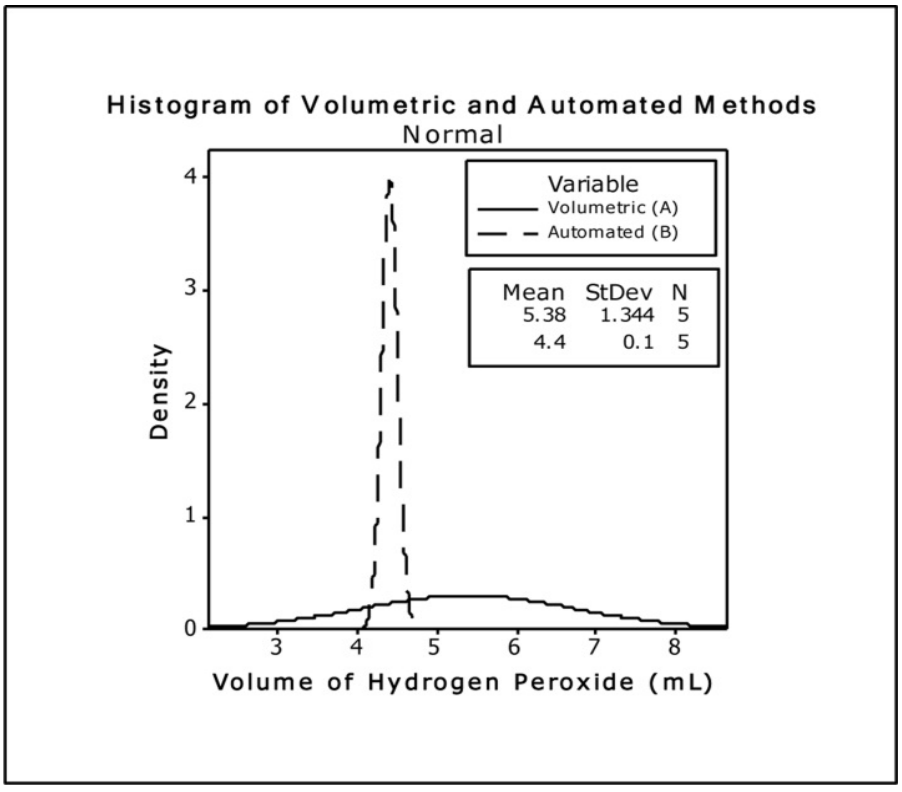

Figure 3. Normal histogram of method (A) and method (B)

The chemical analysis of the H_2O_2 sample using the $KMnO_4$ standard solution resulted in five trials of $KMnO_4$ volumes by methods (A) and (B). The readings were used to calculate the mean value and the concentration of H_2O_2. The concentrations calculated by methods (A) and (B) were 0.13 and 0.11M, respectively. We aimed to determine whether the results obtained in method (A) differed from those obtained in method (B). One way to answer this question was to construct probability distribution curves for each method, and compare the curves to one another. An ambiguous situation appeared, as is demonstrated in Figure 3. Although the means for the two methods were different, the probability distribution overlapped to the extent that a significant number of the possible volume readings could have belonged to either distribution. In this case, we could only conduct a significance test to determine whether there was a difference between the two methods. The answer yes or no is simply referred to as the null hypothesis, H_0, indicating that the indeterminate error was sufficient to explain any differences found between the methods being compared. In contrast, the alternative hypothesis, H_A, is that the difference between the two methods is too great to be explained by an indeterminate error [17, 23].

A two-tailed *f*-test of the following null hypothesis $H_0 : s_A^2 = s_B^2$ and alternative hypothesis $H_A : s_A^2 \neq s_B^2$ was used to determine whether a pooled standard deviation could be calculated using Eq.1.

$$f_{\text{exp}} = \frac{1.34_A^2}{0.1_B^2} = 179.56$$

Since f_{exp} is larger than the critical value of 9.605 for $f_{(0.05, 4,4)}$, the null hypothesis is rejected, and the alternative hypothesis that the variances are significantly different is accepted. As a result, a pooled standard deviation cannot be calculated.

The mean values obtained by the two methods are compared using a two-tailed *t*-test. The null hypothesis is $H_0 : \bar{x}_A = \bar{x}_B$, and the alternative hypothesis is $H_A : \bar{x}_A \neq \bar{x}_B$.

Since a pooled standard deviation could not be calculated, the test statistic, t_{exp}, is calculated using Eq.2.

$$t_{exp} = \frac{|5.38 - 4.40|}{\sqrt{(\frac{1.38_A^2}{5_A}) + (\frac{0.10_B^2}{5_B})}} = 1.63$$

and the degrees of freedom (DF) are calculated using the following equation:

$$\mathrm{DF} = \frac{[\left(\frac{S_A^2}{n_A}\right)+\left(\frac{S_B^2}{n_B}\right)]^2}{\left[\frac{S_A^2}{n_A}/(n_A+1)\right]+\left[\frac{S_B^2}{n_B}/(n_B+1)\right]} - 2 \qquad (5)$$

$$\mathrm{DF} = \frac{[\left(\frac{1.34_A^2}{5_A}\right) + \left(\frac{0.10_B^2}{5_B}\right)]^2}{\left[\frac{1.34_A^2}{5_A}/(5_A + 1)\right] + \left[\frac{0.10_B^2}{5_B}/(5_B + 1)\right]} - 2 \cong 4$$

The critical value for $t_{(0.05,4)}$ is 2.78. Since the calculated value of t_{exp} is less than $t_{(0.05,4)}$, the null hypothesis is retained and the alternative hypothesis is rejected. Moreover, there is no evidence that the two methods are significantly different at the chosen significance level (p=0.05).

If the null hypothesis is retained, then any differences are due to an indeterminate error. Analysts describe several causes of indeterminate errors (*e.g.*, the collection of samples, the manipulation of samples during analysis, human error when taking measurements).

6. Conclusions

H_2O_2 was studied from the point of view of different scientific branches in order to demonstrate the interrelationships and relevance of the sciences, based on the centrality of chemistry, and to confirm that the health sciences should be multidisciplinary. Experimental and theoretical explanations are highly recommended to integrate the scientific educational pedagogy for health sciences students.

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