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Green Chemistry: Approach to Improve the Performance of Grade 11 STEM Students in Chemical Equilibrium

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ABSTRACT

Most science activities and programs provide emphasis on saving the environment. The Green Chemistry approach matches this effort to enhance students' understanding of chemical concepts at the same time promote the value of responsible stewardship by applying principles that reduce or eliminate the use or generation of hazardous substances in the design of laboratory activities.

This study focused on the use of Green Chemistry to improve the performance of Grade 11 students in Chemistry particularly on the topic on chemical equilibrium.

This action research employed the experimental design where the 205 Grade 11 STEM students enrolled during the second semester of the school year 2019-2020 were exposed to two Green Chemistry laboratory activities in chemical equilibrium.

The pretest and posttest data were analyzed using appropriate statistical measures namely: highest possible score, highest score obtained, lowest score obtained, mean, mean percentage score, median and standard deviation. The level of performance of the Grade 11 STEM students were further described as high, average or low. Paired samples t-test analysis of students' pretest and posttest assessments was carried out at 0.05 level of significance.

The results of the pretest revealed an "average" level of performance among the Grade 11 STEM students. Higher scores are evident during the posttest showing a "high" level of performance. The effectiveness of the Green Chemistry approach was further established by comparing the performance of the Grade 11 students in the pretest and posttest. Their posttest scores were significantly higher than their pretest scores. The results suggest that the green chemistry approach is effective in improving the students' performance in Chemistry specifically in their understanding of one of the most complex topics which is chemical equilibrium.

Prior to the intervention, most students held misconceptions about chemical equilibrium. However, after using the green chemistry approach, they gave logical explanations about systems in equilibrium and how they were affected by external stresses. The Green Chemistry hands-on activities helped the students to improve their performance in chemistry by reinforcing the development of students' concepts in chemical equilibrium while taking measures to save the environment. It is recommended that the green chemistry teaching approach be adopted by other chemistry teachers in Urdaneta City Division. Similar approach can also be used in teaching other science concepts.

The study shows that the Green Chemistry approach greatly improved the Grade 11 STEM students' understanding of Chemical Equilibrium. Pre-test scores averaged 7.81 with no high performers, while post-test scores rose to 15.15, with 63.4% of students achieving high performance. A paired t-test confirmed a significant improvement ($p < .05$), proving the effectiveness of Green Chemistry in teaching complex topics. Additionally, the approach promoted environmental awareness, making it a valuable teaching method for broader use in science education.

Keywords: green chemistry, chemical equilibrium, interventions

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INTRODUCTION

The Science, Technology, Engineering and Mathematics (STEM) strand of the Philippine K to 12 Enhanced Basic Education Curriculum is designed to produce graduates of secondary level who will take science, research, math and engineering-related courses in college and thereby add to the scientific workforce. This affirms that senior high school is a critical phase of education and that understanding of concepts in specialized subjects for STEM is very crucial.

The researchers are teachers of General Chemistry 1 and 2, the first set of specialized science subjects which the Grade 11 STEM students of Urdaneta City National High School are exposed to. In their years of teaching in the senior high school, the researchers have made similar observations. STEM students have great difficulty in applying the learned concepts or in understanding the main topics in General Chemistry. The researchers have a growing concern for the Grade 11 students that they may not be able to perform to their fullest capacity. The STEM students must develop knowledge and skills of Chemistry concepts that they will need in their future coursework and careers. If teachers fail to enable these students to learn Chemistry, it can potentially limit their success in their careers and in life.

Santos and Guidote (2015) mentioned in their work what Padolina and Magno (2003) stressed: that while Chemistry and the other sciences are being promoted in the Philippines as experimental subjects and practical works are emphasized, actual practice does not meet the objectives. The minimal application of science through the performance of actual laboratory activities affects the advancement of chemical education in the Philippines.

Layton (1990), as cited by Tesfamariam et al. (2014), argued that chemistry without practical work was seen as a body of factual information and general laws, which conveyed nothing of lasting power to the mind. Hence, laboratory activities in learning Chemistry is very important. In the case of Urdaneta City National High School, the supply of laboratory apparatuses is more than enough, however, insufficient laboratory rooms, inadequate budget for chemicals and other materials, big classes and crowded classrooms are perennial problems. Being aware of the situation in the school level, which is not so different from the situation in the national or even in the international scene, the researchers, as teachers of Chemistry, are responsible in promoting quality chemical education by establishing means to contribute to the solution.

With all science activities and programs providing emphasis on saving the environment, the researchers want to explore on utilizing laboratory activities in teaching chemistry concepts while also focusing on concerns about the environment. As readings are made, the researchers came across Green Chemistry. The Green Chemistry approach matches the researchers' desire to enhance students' understanding of chemical concepts at the same time promote the value of responsible stewardship by applying principles that reduce or eliminate the use or generation of hazardous substances in the design of laboratory activities.

Moreover, based on literature reviews, chemical equilibrium is considered to be the single most difficult topic taught in General Chemistry (Swanson, 2011). This is confirmed in the study of Tilahun and Tirfu (2016) which revealed that students are being more challenged by Chemistry topics particularly Chemical Equilibrium. It is at the above cited scenarios that this study focused on the use of Green Chemistry to improve the performance of Grade 11 STEM students in Chemistry particularly on the topic on chemical equilibrium.

Research Questions

The following research questions guided the researchers in investigating the use of Green Chemistry to enhance the understanding of chemical equilibrium concepts by the Grade 11 STEM students enrolled in General Chemistry 2 during the second semester of the school year 2019-2020.

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1. What is the level of performance of the Grade 11 STEM students in Chemistry before using the Green Chemistry approach?
2. What is the level of performance of the Grade 11 STEM students in Chemistry after using the Green Chemistry approach?
3. Is there significant difference in the level of performance of the Grade 11 STEM students in Chemistry before and after using the Green Chemistry approach?

Research Hypothesis

The research hypothesis will be tested in its null form at .05 level of significance stated as: there is no significant difference in the level of performance of the Grade 11 STEM students in Chemistry before and after using the Green Chemistry approach.

PROPOSED INNOVATION, INTERVENTION AND STRATEGY

The researchers have drawn their interest in using green chemistry principles to enhance the understanding of Grade 11 STEM students of chemical equilibrium concepts.

Anastas and Warner (1998), proponents of green chemistry in their seminal work entitled "Green Chemistry: Theory and Practice" defined green chemistry as the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and application of chemical products.

Santos and Guidote (2015) stated that Green Chemistry is not a new independent branch of chemistry nor an isolated field on its own, but it penetrates through all of the classical branches of chemistry. It is a chemical philosophy – a way of looking at how things should be done in the practice of chemistry.

Green chemistry is founded on twelve principles as presented by Anastas and Warner.

Table 1 Twelve Principles of Green Chemistry Theory and Practice

Principles	**Explanation**
Prevention	It is better to prevent waste than to treat or clean up waste after it has been created
Atom Economy	Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
Less Hazardous Chemical Syntheses	Whenever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
Design Safer Chemicals	Chemical products should be designed to effect their desired function while minimizing their toxicity
Safer Solvents and Auxiliaries	The use of auxiliary substances- solvents, separation agents, and others- should be made unnecessary whenever possible and innocuous when used.
Design for Energy Efficiency	Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
Use Renewable Feedstocks	A raw material or feedstock should be renewable rather tha depleting whenever technically and economically practicable.

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Reduce Derivatives	Unnecessary derivatization- use of blocking groups, protection/deprotection, and temporary modification of physical/chemical processes- should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
Catalysis	Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
Design for Degradation	Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
Real-time Analysis for Pollution Prevention	Analytical methodologies need to be further developed to allow for real-time, in process monitoring and control prior to the formation of hazardous substances.
Inherently Safer Chemistry for Accident Prevention	Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

This action research integrated some green chemistry principles as it utilized hands-on activities through laboratory work to improve the performance of STEM students in chemistry especially on the understanding of chemical equilibrium. Green chemistry will replace commonly-used chemistry procedures that can be hazardous to the environment. It encourages safe, energy-efficient, non-toxic processes and products in an effort to help alleviate current environmental problems.

In this study, green chemistry replaced the traditional cobalt chloride ion, and iron (III) thiocyanate equilibrium reactions. These chemicals are toxic and hazardous to the environment, aside from the fact that these are inaccessible and expensive chemicals.

The students used an iodine-starch and a tea-vinegar equilibrium in demonstrating concentration changes, temperature changes and shifts when conditions are altered. In this manner, the experiments emphasized the chemical nature of common place materials like cooking ingredients, condiments and the like by using them instead of laboratory chemicals in the activities to make the obvious linkage of chemistry concepts in the lives of the students.

Specifically, the Grade 11 STEM students were exposed in two straight hours to two green chemistry laboratory activities (Appendix G). These activities were adapted from the Green Chemistry and Sustainable Science by Beyond Benign from 2017 www.beyondbenign.org. Modifications were made to suit the type of learners and the availability of materials (Appendix G). The first activity helped the students to form their own concepts about the effect of change in concentration of reactants and products in an equilibrium mixture on equilibrium position. The second activity extended the students' understanding about the effect of change in temperature on equilibrium. Through follow up questions, the students have explained the effect of changes in concentration and temperature on equilibrium position by using only observed color changes.

RESEARCH METHODS

This research employed the experimental design where the grade 11 STEM students were exposed to hand-on activities in chemical equilibrium through the Green Chemistry approach.

Participants Of The Study

A total of 205 Grade 11 STEM students were purposely selected to engage in two (2) Green Chemistry activities on chemical equilibrium. These students are distributed in the five (5) different sections namely: 11-Tesla (40), 11-Landsteiner (43), 11-Euclid (45), 11-Fleming (39) and 11-Descartes (38).

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Data Gathering Methods

To achieve the desired consistency of results employing the experimental design, data collection involved chemical equilibrium concept understanding tests in the form of pretest and posttest. The pre-test was administered on February 12-13, 2020 to determine the level of performance of the grade 11 STEM students before using the green chemistry approach in teaching chemical equilibrium. The green chemistry laboratory activities were performed on March 2-3, 2020. The post-test was conducted on March 10-11, 2020 with data used to establish the level of performance of the grade 11 STEM students in chemistry after using the green chemistry approach.

Data Analysis Plan

The pre-test and post-test data were analyzed using appropriate statistical measures namely: highest possible score, highest score obtained, lowest score obtained, mean, mean percentage score, median and standard deviation. The level of performance of the Grade 11 STEM students were further described using the following score ranges:

Score Range	Descriptive Equivalent
14 – 20	High
7 – 13	Average
0 – 6	Low

The level of performance of the Grade 11 STEM students were further established and compared by determining the frequency and percentage of students with high, average and low performances.

Paired samples t-test analysis of students' pretest and posttest assessments was carried out at 0.05 level of significance to determine if significant difference exists. The tallied scores were analyzed using the paired t-test online calculator athttps://mathcracker.com/t-test-for-paired-samples? which was accessed on March 13, 2020.

DISCUSSION OF RESULTS AND REFLECTION

The pre-test is composed of 20 test items distributed in the different learning competencies covering the topic Chemical Equilibrium as indicated in the Table of Specification for the Pretest.

Table 2 presents the level of performance of the grade 11 STEM students during the pre-test.

Table 2 Level of Performance of the Grade 11 STEM Students in Chemistry before using the Green Chemistry Approach

N = 205

Statistical Measure	Value
Highest Possible Score	20
Highest Score Obtained	13
Lowest Score Obtained	2
Mean	7.81 (Average)
Mean Percentage Score	39.05%
Median	8
Standard Deviation	2.26

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Legend:

Score Range	Descriptive Equivalent
14 – 20	High
7 – 13	Average
0 – 6	Low

The highest score obtained is 13 while the lowest is 2. This gives a range of 9. The mean score of the grade 11 STEM students in the pre-test is 7.81 which denotes an average level of performance. The mean percentage score (MPS) of 39.05 indicates that on the average, the students have correctly answered 8 out of 20 test items. The median of 8 denotes that half of the number of students who took the pre-test scored above 8. The standard deviation is 2.26.

Table 3 on the next page displays the level of performance of the grade 11 STEM students in chemistry as reflected in their scores during the post-test, that is, after the students perform the green chemistry laboratory activities in chemical equilibrium.

Table 3 Level of Performance of the Grade 11 STEM Students in Chemistry after using the Green Chemistry Approach

N = 205

Statistical Measure	Value
Highest Possible Score	20
Highest Score Obtained	20
Lowest Score Obtained	12
Mean	15.15 (High)
Mean Percentage Score	75.75%
Median	15
Standard Deviation	2.32

Legend:

Score Range	Descriptive Equivalent
14 – 20	High
7 – 13	Average
0 – 6	Low

The post-test is composed of 20 test items which are parallel to the test items in the pre-test as shown in the table of specification for the post-test (Appendix C).

The highest score obtained is 20 out of the 20 post-test items. The lowest score obtained is 12. The mean score is 15.15 described as a high level of performance with a corresponding mean percentage score (MPS) of 75.75. The MPS value indicates that on the average, 15 out of 20 test items were answered correctly by the students.

The value of the median has notably increased to 15. This implies that half of the scores obtained by the grade 11 STEM students are higher than 15. The standard deviation has slightly increased to 2.32 indicating that the scores of the students in the post-test are more dispersed compared to their pre-test scores.

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The data presented during the pre-test and post-test have shown that higher scores are evident during the post-test which was administered to the students right after the green chemistry laboratory activities have been performed by the grade 11 STEM students. The increase in scores confirms that the performance of the students has improved during the post-test. The increase in scores also indicates the effectiveness of the green chemistry laboratory activities in improving the performance of the grade 11 STEM students particularly in their understanding of Chemical Equilibrium.

Table 4 shows the distribution of the students according to their level of performance in chemistry before using green chemistry through the pre-test, and after using green chemistry based on the post-test scores.

As indicated in the comparative table on the next page, 30% of the grade 11 STEM students have performed low in the pre-test while the remaining 70 percent got average scores. After employing the green chemistry laboratory activities in chemical equilibrium, none among the students have performed low. Seventy-five of them (36.6%) have average performance while majority (130 or 63.4%) got high level of performance.

Table 4 Comparative Table Showing the Level of Performance of the Grade 11 STEM Students before and after Using the Green Chemistry Approach

N = 205

Level of Performance	**Before using Green Chemistry (Pre-test)**			**After Using Green Chemistry (Post-test)**	
	f	**%**		**f**	**%**
High (14-20)	0	0.0		130	63.4
Average (7-13)	144	70.0		75	36.6
Low (0-6)	61	30.0		0	0.0

The data set reinforces the earlier claim that the green chemistry laboratory is effective in improving the ‘performance of the grade 11 STEM students in Chemistry particularly on the topic Chemical Equilibrium.

To further test the statistical significance of the difference in the mean scores between the pre-test and post-test, the paired samples t-test have been employed with the results presented in Table 5.

Table 5 Paired t-Test Result on the Performance of the Grade 11 STEM Students Before and After Using Green Chemistry Approach

N = 205

	Mean	**Mean Difference**	**Standard Error of the Mean**	**t-value**	**df**	**p-value**
Pre-test	7.81	-7.74	0.197	-37.26	204	.00
Post-test	15.15					

As presented in the previous tables, the mean scores of the grade 11 STEM students in the pre-test and post-test are 7.81 and 15.15, respectively. The negative mean difference of -7.74 indicates that the post-test scores are higher than the pre-test scores. Since it is observed that the t-value is -37.26 at df of 204 and the p- value is 0 which is less than the set .05 level of significance, it is concluded that the null hypothesis is rejected. The results are statistically significant, therefore, there is enough evidence to claim that there is significant difference between the pre-test and post-test scores. A one-tailed test also indicated that the post-test scores are significantly higher than the pre-test scores. Hence, the green chemistry laboratory activities were effective

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in improving the performance of the grade 11 STEM students in Chemistry particularly along the topic Chemical Equilibrium.

The current results support the outcome of the investigation conducted by Hanson (2016) where small scale science activities were found to be effective in enhancing students' conceptual understanding of equilibrium shifts.

The simple green chemistry laboratory activities exposed the grade 11 STEM students to influencing factors in equilibrium conditions aside from the fact that observation and achievement of results were fast and fun. This implies that teachers can engage their students to similar activities in the course of their lesson to enable them to capture authentic concepts. If students engage in learning by investigating, collaborating and discussing, they gain more meaningful learning and become more responsible about safety and environment as revealed in this study.

The activities helped the students to improve their performance in chemistry by reinforcing the development of students' concepts in chemical equilibrium while taking measures to save the environment. It is hoped that the green chemistry teaching approach be adopted by other chemistry teachers in Urdaneta City Division. Similar approach can also be used in teaching other science concepts. Furthermore, other equally good teaching approaches can also be explored by teachers to enhance conceptual understanding of science principles.

CONCLUSION

The results of the study indicate that the Green Chemistry approach significantly improved the performance of Grade 11 STEM students in understanding Chemical Equilibrium. The pre-test scores revealed an average performance, with a mean score of 7.81 and no students achieving high performance. After implementing Green Chemistry laboratory activities, the post-test scores demonstrated a significant increase, with a mean score of 15.15 and 63.4% of students reaching high performance levels. The paired t-test analysis further supported these findings, showing a statistically significant difference between pre-test and post-test scores ($p < .05$). This demonstrates the effectiveness of integrating Green Chemistry principles in enhancing student understanding of difficult chemistry topics like Chemical Equilibrium.

The activities not only improved conceptual understanding but also promoted environmental awareness, which aligns with the goals of modern science education. The success of this approach suggests that it can be adopted by other educators and applied to different scientific concepts, contributing to the improvement of science education at Urdaneta City National High School and beyond.

Plans For Dissemination And Utilization

On the basis of the findings obtained in the present investigation, the following are the plans for dissemination and utilization:

1. Inform the school head of the salient findings of the study and plan for dissemination of results to parents and teachers.
2. Present the findings of the study to the Public Schools District Supervisor, Chief of the School Governance and Operations Division and to the Chief of the Curriculum Implementation Division.
3. Disseminate results of the present study to the senior high school science teachers through School-Based Learning Action Cell (SLAC) Session.

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Ethical Considerations

These principles include voluntary participation, informed consent, anonymity, confidentiality, potential for harm, and results communication.

Data Availability

No data is publicly available. This manuscript is categorized as unique manuscript.