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TEACHING CHEMISTRY THROUGH THE IDENTIFICATION OF SCIENCE PROCESS SKILLS INVOLVED IN THE EXTRACTION OF CAFFEINE FROM *COLA ACCUMINATA*

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ABSTRACT

This research explored the science process skills in extracting caffeine from cola accuminata. The method used in this study was pure experimental research design. The study population was 1,856 senior secondary 2 (SS 2) Chemistry students. A sample of 82 SS2 Chemistry students was randomly drawn from four public schools in the Otuocha Education Zone. Two research questions and one hypothesis guided the study. The instrument used for data collection was the validated Process Skills Observation Guide (PSOG). The PSOG was developed by an experienced educational Psychologist with the researchers. The PSOG was tailored to detect the process skills in extracting caffeine from cola nuts. The instrument consists of 17 items rated on 4 point scale. Mean and standard deviation were used to answer research questions, while the z-test was used to examine the hypothesis at the significance level of 0.05. It was observed that most of the science process skills listed involved extracting caffeine from cola nuts, thereby making the understanding of Chemistry concepts more real than abstract. Based on the findings, some recommendations were made for the teachers, students, school administrators and guardians.

Keywords: Caffeine, Chemistry, Extraction, Kola Nut, Science Process Skills

INTRODUCTION

Education is a crucial instrument for empowering children to take care of their lives in the future. Science education aims to help students understand scientific processes and manipulate the various scientific methods. Understanding basic concepts is essential for almost every profession. For Nigeria to advance in science and technology, much priority must be given to promoting scientific knowledge and skills. Science education combines science knowledge with the study of education (Nnoli & Onwudinjo, 2024). Science as a process is used in obtaining

science products such as some concepts, principles, theories, and laws. Science is about the discovery of skills to solve problems. Science is a body of knowledge that has been organized by careful collection and analysis of data. Science is necessary for the technological development of the quality of scientists produced by the education system. Njelita (2017) defined science as an organized body of knowledge based on facts and tested truths arranged in an orderly system. The basis for describing what science is all about are the cognitive skills, process skills, development of scientific attitudes and manipulative skills. Science consists of, among other components, Chemistry, Physics, Biology, Mathematics, etc. Among these, Chemistry is one of the science subjects offered in all the senior secondary schools in Nigeria attracting the most significant number of science-oriented students. Nnoli (2014), stated that Chemistry is a discipline in which teachers and researchers may amplify high standards of conduct in ways that students fail to observe. As an accumulated body of knowledge, chemistry stands in a central position among the basic sciences from which technologists derive their scientific principles to create wonders. Chemistry is a great subject responsible for environmental activities (Udegbunam, 2024). Chemistry, as a subject that studies the nature, properties, composition, reaction and changes which matter undergoes, is a central science subject since all these concepts are fundamental to all life processes.

Process skills are ways of thinking about and interacting with materials and phenomena that can lead to understanding new scientific ideas and concepts. The processes of undertaking science are the science process skills. According to Kruea-in & Thongperm (2014), science process skills can be categorized into two levels: basic and integrated. Basic science process skills consist of observing, classifying,

measuring, using numbers, using space and time relationships, inferring, predicting, and communicating. Integrated science process skills include identifying variables, formulating hypotheses, defining variables operationally, experimenting and interpreting data, and drawing conclusions (Nnoli & Onwudinjo, 2024). Constructing and inferring data and images, which can lead to changing hypotheses, will help children grow as individuals with high mental processes capable of solving individual and social problems. Process skills enable students to describe concepts, make predictions, raise questions, examine predictions and interpret data (Komang *et al.,* 2021). All these equip the students for entrepreneurship.

Integrating science process skills into Chemistry education enhances students' ability to engage critically with scientific concepts and apply them to real-world scenarios. In teaching Chemistry, focusing on practical methods like the extraction of caffeine from Cola accuminata provides an engaging framework to explore vital scientific processes. These processes, including observation, inference, prediction, measurement, and classification, are integral to understanding Chemistry as a discipline and developing analytical competencies necessary for innovation and problem-solving.

Caffeine extraction offers a compelling case study for introducing students to separation techniques such as liquid-liquid extraction and recrystallization. These methods clarify fundamental chemical principles and encourage the development of hands-on skills crucial for scientific inquiry. As demonstrated in recent studies, such interactive experiments foster a more profound comprehension of chemical reactions, solubility principles, and the polarity of compounds (Komang *et al.,* 2021; KCL Chemistry Outreach, 2023).

Moreover, incorporating locally relevant materials like *Cola acuminata* connects scientific learning with students' cultural

and environmental contexts. The extraction of caffeine—a compound widely recognized for its stimulatory effects and applications in pharmaceuticals and energy drinks—provides an authentic example of Chemistry's role in improving human well-being (Gupta & Maurya, 2023).

By utilizing experiments such as caffeine extraction, educators can better demonstrate the intersection of theoretical and practical Chemistry, equipping students with the skills to analyze, interpret, and apply scientific concepts. This approach advances their academic performance and prepares them for careers in science and technology, fulfilling the broader goals of science education to support societal advancement (Azonuche, 2021; Komang *et al.*, 2021).

The scientific practices enhance the understanding of Chemistry in the following ways:

1. **Observation:** Making observations is fundamental to all learning. Observations accumulate data from which inferences will be drawn. Careful observation of chemical phenomena allows chemists to identify patterns and anomalies, leading to discoveries and insights (Azonuche, 2021).
2. **Classification is the grouping or ordering of phenomena according to an established scheme.** Organizing elements, compounds, and reactions into categories and hierarchies helps identify relationships, trends, and exceptions, facilitating understanding and prediction.
3. **Communication:** Clear and concise communication of ideas, methods, and results enables collaboration, verification, and building upon existing knowledge. (Kurniawan *et al.*, 2023).
4. **Measurement:** Quantifying physical and chemical properties, such as mass,

volume, and concentration, provides precise data for analysis and modelling (Gizaw & Sota, 2023).

5. **Inference:** Inference leads to prediction based on evaluation and judgment based on experiences. Drawing logical conclusions from observations and data enables chemists to formulate hypotheses, theories, and models that explain chemical behaviour.
6. **Prediction:** This is an expected result based on experience, and its reliability depends upon the accuracy of past observations. Using theories, models, and data to forecast chemical properties, reactions, and outcomes allows chemists to design new experiments, materials, and applications. These skills collectively contribute to a comprehensive scientific approach.
7. **Resilience:** coping with setbacks, failures and rejection; learning from mistakes and integrating feedback.
8. **Optimization** is the achievement of maximum efficiency and productivity through streamlining processes. It involves identifying bottlenecks, saving costs, better resource allocation, and enhancing productivity.

By employing these scientific practices, chemists can systematically investigate, understand, and apply chemical principles to various phenomena, from molecular interactions to macroscopic processes and laboratory experiments to real-world applications.

Despite the key role of Chemistry as the central science that forms the basic foundation in many disciplines and in improving the quality of life, the performance of Nigerian secondary students in the subject has for many years remained a matter of grave concern (Oloyede, 2010). Teaching is transmitting

skills to a learner, attending to people's needs and giving instructions, especially in the institution of learning. Therefore, a teacher, as a person who helps learners gain information, competence, and virtue through teaching, needs to employ various strategies to impact the students. The purpose of teaching Chemistry in schools is to enable the students to develop these skills and knowledge in chemical science and become beneficial to themselves and society (Abbas, 2011). In teaching Chemistry, it is expected that the teacher should have a good level of competency and mastery of the subject. A good understanding of the science process skills by the science (Chemistry) teachers will help the teachers transfer the knowledge to the students.

The cola nut tree is native to West Africa; Pharmcopea's name is colae semen, while its other names include Kola nut and Gurunut. Of the forty (40) known species, Cola accuminata and Cola nitida bear the nuts most readily available in Africa. Today, cola nuts are exported worldwide and used to manufacture methylxanthine-based pharmaceuticals and produce energy drinks. Kola Nut contains around 3 percent caffeine (1, 3, 7 – trimethyl – 1H – purine – 2, 6 (3H, 7H) – Dione, Molecular formula – $C_8H_{10}N_4O_2$, Molecular mass – 194.19 g/mole Melting point – 238° C) and around 2 percent theobromine (Ifiora *et al.*, 2013). Both of these compounds act as "vasodilators". This raises the oxygen levels in the brain, boosting cognitive function and alertness. Additionally, its high caffeine content inhibits the production of adenosine, the neurotransmitter that promotes sleep and suppresses arousal, thus enhancing alertness and focus and improving reaction time and physical energy. Kola Nut tincture (ethanol extract) significantly lowered glucose levels (Duze *et al.*, 2012).

Kola nut acts as an appetite suppressant because Cola nut dramatically decreases their overall calorie consumption. This act

is because of the action of caffeine present in Kola nut, and it is the primary mechanism of Energy Drink. According to Gupta & Maurya (2023), caffeine, one of the components of Kola nut, may help protect human brain cells, lowering the risk of developing some diseases, such as Parkinson's. Caffeine causes the blood vessels to constrict, which may help relieve some headaches, pain, and asthma attacks. Caffeine creams are applied to the skin to reduce redness and itching in dermatitis.

Extraction in Chemistry is separating a substance from a matrix (Lisa, 2022). It can also be defined as a common technique used in organic Chemistry to isolate a target compound. In extraction, a solute is transferred from one phase to another to separate it from unreacted starting materials or impurities. The equilibrium constant that governs the distribution of a solute, S, between two immiscible solvents is called the distribution coefficient or partition coefficient, K:

$$K = \frac{Concentration\ of \text{ solute in organic solvent}}{Concentration\ of \text{ solute in aqueous solvent}}.$$

After extraction, the extract will be concentrated using a rotary evaporator. This ensures that the evaporation is done at a reduced temperature to avoid denaturing any components. The process is then followed by proper separation of the extract's elements.

Chromatography

Chromatography separates, purifies, and tests compounds (Roy & Calvin, 2024). The mixture to be separated is applied on a stationary phase, carrying the components separately according to their solubility in the eluent (pure solvent or solvent mixture). The technique is based on a polarity interplay between the sample and two other substances, the solid (or stationary) phase and the mobile phase, which can be a liquid or a gas. Each sample component elutes from the stationary phase at a specific retention time (retention factor value, RF value).

$$Rf = \frac{distance\ moved\ by\ the \text{ solute}}{distance\ moved\ by\ the \text{ solvent}}.$$

Recrystallization

Recrystallization (or Crystallization) is a technique used to purify solids. This procedure relies on the fact that solubility increases as temperature increases. As a hot, saturated solution cools, it becomes supersaturated, and the solute precipitates (crystallizes) out. When the solvent's polarity, acidity, or basicity changes, this helps crystallize the crystals.

Statement of the Problem

The high rate of unemployment in Nigeria is alarming. Not even minding that the nation is blessed with many natural resources, most of the exports done in the country are crude or raw materials instead of finished products, which will earn the country more income. This ugly situation may be because our young graduates do not have the skills needed for such innovation. This renders these young graduates unemployable and unemployed. With the use of activity-based teaching to the students, such as the extraction of caffeine from cola accuminata (Onwudinjo, 2024), they will be able to acquire the skills necessary to be self-reliant. This necessitated investigating the process skills that Chemistry students can develop by extracting caffeine from Cola Accuminata.

Purpose of the Study

This research aims to examine the teaching of Chemistry by identifying science process skills in extracting caffeine from Cola accuminata. Specifically, the study sought to:

1. Determine the science process skills involved in extracting caffeine from Cola accuminata.
2. Determine the extent of gender influence on the acquisition of science process skills during the extraction of caffeine from cola nut.

Research Question

The following research questions guided the study:

1. What are the science process skills involved in extracting caffeine from Cola accuminata?

2. What is the extent of gender influence on the acquisition of science process skills during the extraction of caffeine from cola nut

Research Hypothesis

The null hypothesis was tested at a 0.05 level of significance.

There is no significant difference between male and female students in acquiring science process skills during the extraction of caffeine from Cola accuminata.

METHODOLOGY

Sampling

The study was carried out in a senior secondary school in Anambra East Local Government Area (LGA) of Anambra State. It is a pure experimental research design with a population of 1,856 SS2 Chemistry students. The sample of the study is eighty-two (82) SS 2 Chemistry students drawn from four public schools in the LGA using a simple random sampling technique. The instrument used for data collection was the validated Process Skills Observation Guide (PSOG). The PSOG was developed by an experienced educational Psychologist with the researchers. The PSOG was tailored to detect the process skills in extracting caffeine from cola nuts. The instrument consists of 17 items rated on 4 point scale. Mean values of 2.50 and above indicated that it is significant, while those below 2.50 were not significant to the students, which is rejected.

Extraction Process

The cola nut was first air-dried. The air-dried cola nut was finely ground using a grinding machine. The ground cola nut was placed on a weighing balance to determine the mass. Slaked lime was also weighed and then mixed with the weighed cola nut. The intimated cola nut / slaked lime mixture was soaked in 200mL boiling 96% ethanol for 90 minutes using a water bath. Two more extractions were subsequently made. These extracts were combined, filtered and left to stand overnight, followed by cold filtration. The filtrate was then concentrated using a rotary evaporator. The residual solution

was poured into a covered dish and allowed to stand at room temperature away from the draught. A fleecy mass of long, flexible, whitish crystals possessing silky lustra with a bitter taste and no odour was observed. The purity of the extract was tested using chromatography. A paper chromatographic test was carried out on the crystalline ethanol extract with the eluent n-butanol: concentrated HCl solvent mixture in the ratio of 9:1. Two spots were observed, indicating two components in the extract. The melting point of the crystal gave a broad range of 236-238°C. Further purification was done by dissolving the extract in boiling water, then cooling, filtering, and recrystallization. The chromatogram gave one spot while the melting point was sharp at the temperature of 236°C.

RESULTS AND DISCUSSION

Research Question 1. What are the science process skills involved in extracting caffeine from *Cola accuminata*?

Table 1: Mean rate score and standard deviation of Chemistry student's awareness of science process skills involved in extracting caffeine from cola nut.

S/n	Science Process Skills	Mean X̄	Standard Deviation (SD)
1.	Observing	2.96	0.40
2.	Classifying	2.23	1.14
3.	Communicating	2.13	1.20
4.	Measuring	2.72	1.41
5.	Counting and using numbers	2.85	0.50
6.	Inferring	2.52	1.13
7.	Predicting	2.54	1.05
8.	Experimenting	2.70	1.43
9.	Questioning	3.33	0.82
10.	Manipulating	2.80	0.41
11.	Formulating hypothesis	2.10	1.00
12.	Controlling variables	2.58	0.94
13.	Formulating models	2.52	1.13
14.	Interpreting data	2.65	1.24

15.	Making operational definitions	2.50	1.12
16.	Optimizing	2.80	0.41
17.	Resilience	1.83	0.99
	Total	**43.49**	

Table 1 presents the mean scores and standard deviation of the scientific process skills achieved in extracting caffeine from cola nuts. The mean scores showed that the students acquired thirteen (13) out of the seventeen (17) process skills. This indicates an increase in process skill acquisition in the extraction of caffeine from cola nuts.

Research Question 2: What is the extent of gender (male and female) on acquiring science process skills during the extraction of caffeine from cola nut**:**

Table 2: Mean rating scores of gender influence (male and female) on acquiring science process skills.

Gender	No. of Students	Mean	Standard Deviation
Male	33	2.60	0.68
Female	49	2.69	0.86

Table 2 shows that the mean score of the female students is higher than that of their male counterparts, indicating that the female students acquired more process skills than the male students.

Hypothesis: Process skills acquisition rates are statistically equivalent for male and female students in extracting caffeine from cola nuts; there is no significant gender-based difference.

Table 3: z-test of the mean ratings of male and female students on the acquisition of science process skills

Gender	No. of students	Mean	SD	diff	z-cal	z-crit
Male	33	2.60	0.68			
				81	0.204	1.960
Female	49	2.69	0.86			

Table 3 shows that the calculated z-value is 0.204, less than the z-critical value, 1.960, indicating that the null hypothesis is accepted. There is no significant difference between male and female students in acquiring science process skills during the extraction of caffeine from cola nuts.

DISCUSSION

From the results, the students identified 13 of the 17 science process skills, indicating that using activity-based teaching, such as extracting caffeine from cola nuts, has impacted the students with process skills, which is the basis of entrepreneurship. Acquiring these basic skills will make them self-reliant, reducing unemployment and crime in society. Their ability to extract caffeine from cola nuts with basified water (optimization) motivated the students to think critically about extracting other metabolites and using the extracts in producing finished products, such as energy drinks, instead of selling or exporting crude (raw) materials. The students explored chemical concepts by varying the basicity and polarity of the solvents used in the extraction. The detailed observations by the students increased their understanding of the basic concepts of separation. The students could infer that a broad melting point indicates impurity (a broad melting point of 235 - 238°C and the appearance of spots in the chromatogram shows the number of components in the extract or mixture). This is a step for the students to acquire forensic skills. Even though there is no significant improvement in the student's communication skills, the students developed manipulative skills and curiosity to explore chemical concepts and phenomena, thus fostering a love for learning, as shown in the mean score of the students' questioning during the demonstration. They were also able to manipulate by changing the solvent pH and polarity to affect solubility in separation. There is a need to improve those skills that

seem insignificant to the students, such as communication, formulating hypotheses, classification and resilience. Resilience is the ability to cope with setbacks, failures and rejection; learning from mistakes and integrating feedback are critical factors that ruin any business; hence, if not adequately taught to the students, it may frustrate their future.

CONCLUSION

Science process skills are the basis for mastering other thinking skills. The result of this study showed that students gave a positive response to the science process skills methodology. Prospective Chemistry teachers need to be trained in science process skills to produce teachers with good science process skills. In line with the Nigerian Universal Basic Education system, students are helped to acquire relevant skills, competencies, and abilities necessary for meaningful living and positive contributions to nation-building (Impact of funding the UBE on Human Capital, 2022). This will help reduce unemployment.

RECOMMENDATIONS

In line with the findings of this study, the researcher recommended:

1. The ministries of education and federal and state schools should provide funds for the provision and acquisition of chemicals and Chemistry lab equipment.

2. Efforts are needed to train prospective Chemistry teachers in science process skills so that teachers with good science process skills are produced, which can lower crime rates, reduce unemployment, etc.

3. Teachers should include or expose the students to practical work or investigations to familiarize them with the essential science process abilities that will enable them to become entrepreneurs.

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