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Crystallography and Chemistry: Enhancing Nigerian Educational Outcomes as Evidenced from a Nigerian University

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Abstract: Education is the best legacy a country can provide to its citizens. As a nation with over 350 distinct ethnic groups and diverse indigenous languages, Nigeria must embrace innovative changes in its education system to foster growth. This study evaluates the integration of crystallography education into the Nigerian curriculum as a transformative approach to enhancing learning outcomes. Grounded in the Technology Acceptance Model (TAM) theory, which highlights Perceived Usefulness and Perceived Ease of Use as critical drivers of technology adoption, this research adopts a quantitative methodology. Using a descriptive research design, 184 questionnaires were randomly distributed across undergraduate students in the Chemistry Education Department, Faculty of Education, Federal University Otuoke, Bayelsa State. Data were analyzed using Descriptive Statistics, One-Sample t-tests, and Paired-Sample t-tests via SPSS version 23.0. Findings underscore the significance of crystallography education in advancing chemistry studies in Nigeria. The study also identifies a substantial readiness in the Nigerian education system to adopt crystallography education, alongside notable challenges that may impede its implementation. Recommendations include the provision of standard teaching/learning materials for secondary schools and higher institutions and capacity-building initiatives to train educators in crystallography applications to support materials science and related fields in Nigeria.
Keywords: crystallography, curriculum, chemistry, education, learning outcomes.

I. INTRODUCTION

Education is the best legacy a country can give to her citizens and Nigeria as a country with diverse cultural diversities of not less than 350 distinct ethnic groups and diverse indigenous languages, should be open for newer changes in the field of learning. As rightly noted by Igbuzor (2006), education is a human right that should be accorded to all human beings solely by reason of being human. Obani (1996) expressed that education improves the development of any society and the youths who occupy significant positions in that country should be properly educated in order to improve the society. Therefore, schools at various levels are expected to educate future leaders and develop the high-level technical capacities needed for economic growth and development (Osokoya, 2008). It is against this background that education has been accorded a prime position worldwide.

Within the context of science education, Chemistry has been identified as a very important science subject and its importance in scientific and technological development of any nation has been widely reported (De-Jong & Talanquer (2015). Chemistry education awareness is growing and providing sound foundation for well-articulated researches and skills development in developed and emerging economies because it is the backbone for sustaining any nation's economy (Mbachu & Hamilton-Ekeke, 2013). Ryan (2018) noted that chemistry education aims at equipping learners with diverse basic scientific skills, competencies and creativity needed to provide opportunities for wealth creation. These aims will remain a mirage if teachers of chemistry do not have the pre-requisite qualification and experience needed for an engaged chemistry interactive classroom to enhance their productivity. Olayiwola (2012) explained that chemistry education plays important role in enhancing the quality of teaching and research as well as ensuring that students are equipped with good knowledge to produce intensive goods and services to meet human needs for food, health care products and other materials aimed at improving the quality of life.

It was as a result of the recognition given to Chemistry in the development of the individual and the nation that it was made a core subject among the natural sciences and other science related courses in Nigerian education system.

Saparlis (2015) explained that learning chemical concepts is not straightforward as students at all levels often do not understand; or only partially understand; or indeed misunderstand; key concepts they meet in their studies of chemistry.

De-Jong and Talanquer (2015) opine that students in these situations are sometimes well aware they are confused or do not understand what is being taught: but that is by no means always the case. Indeed, Saparlis (2015) added that it is not at all unusual for students to only partially understand, or indeed misunderstand, concepts that they think they do understand. According to Ryan (2018), when students present with conceptions that are inconsistent with the target knowledge being taught, their ideas are often labelled using terms such as misconceptions, alternative conceptions or alternative frameworks. Such terms are justified because often (although not always) students' alternative ideas in chemistry are well established and strongly committed to (De-Jong & Talanquer (2015). So, even when the teacher becomes aware that there is an issue, modifying student thinking may not be straightforward (Saparlis, 2015). This is one of the core issues in chemistry education. It has been a pre-requisite subject for offering most science-oriented courses in the tertiary institution and this calls for the need in teaching it effectively.

Rosado-Flores (2020) noted that with the advent of the World Wide Web has come the ease of sharing of data between scientists and science enthusiasts. There are accessible materials for instructors who wish to implement (or create) their own case studies. Unsar and Engin (2013) informed that it is of great importance to study synthetic inorganic chemistry, thus, creating the need to understand what crystallography is all about. Malbrecht, Campbell, Chen and Zheng (2016) explained crystallography as a branch of science that deals with discerning the arrangement and bonding of atoms in crystalline solids and with the geometric structure of crystal lattices. Classically, the optical properties of crystals were of value in mineralogy and chemistry for the identification of substances (Unsar and Engin, 2013). Rosado-Flores (2020) explained crystallography as the science of determining the arrangement of atoms in solid matter. In chemistry, science practical in schools is aimed at giving the students the opportunity to gain meaningful learning, acquire appropriate skills and attitudes that enable them live and contribute to the development of society. This creates the room to deploy crystallography in the study of chemistry education. Grazulis, *et al.* (2015) advised that crystallography can be introduced in secondary school and undergraduate chemistry courses through crystal growth experiments and crystal growing competitions. The aesthetic qualities of nicely shaped crystals can motivate students to further pursue experimental and theoretical studies of crystallography; at the same time they permit educators to introduce various concepts of crystallography and demonstrate a wide variety of chemical and physical processes that take place during crystal growth. Such practical and theoretical courses can also serve as a good preparation for further studies using X-ray diffraction techniques (Grazulis, *et al.*, 2015).

The aim of the study is to appraise the need to adopt changes in the Nigerian education chemistry curriculum through the deployment of crystallography education. Specifically, this study aims at:

1) Evaluating the importance of crystallography education in the study of chemistry.
2) Examining the readiness of Nigerian education system in adopting crystallography education,
3) Appraising the challenges that could hinder the adoption of crystallography education in Nigerian education system.

II. MATERIALS AND METHODS

A. *Design of the Study*

This study employs the quantitative research, using descriptive method research design of the survey type. According to Cohen, Manion & Morrison (2013), quantitative research is defined as the systematic investigation of phenomena by gathering quantifiable data and performing statistical, mathematical or computational techniques while Igho (2017) added that quantitative research gathers information from existing and potential customers using sampling method and sending out online survey, online poll, questionnaire and so on.

B. *Population of the Study*

In this, the researcher considers the students in all the levels of the undergraduate programme of Department of Chemistry Education, Faculty of Education, Federal University, Otuoke, Bayelsa State as the study population. The population of the students in these four (4) levels as at First Semester, 2020/2021 academic session was 246 (Departmental Registration Office). This is the statistics available for now as no new statistics has been published.

Table 1: Study Population

S/N	Level of Students	Number of Students
1	Level 100	46
2	Level 200	65
3	Level 300	86
4	Level 400	49
	Total	246

C. Sample and Sampling Techniques

The sample size comprises of 184 students randomly selected from the four levels of the undergraduate programme of the Department of Chemistry Education, Faculty of Education, Federal University, Otuoke, Bayelsa State. The reason for selecting this number of students is to ensure that at least, 75% of the total population were considered for this study.

Table 2: Sample of the Study

S/N	Level of Students	Number of Students
1	Level 100	32
2	Level 200	51
3	Level 300	65
4	Level 400	36
	Total	184

D. Instrument and Data Collection

A structured questionnaire, developed by the researcher, served as the primary instrument for data collection. The questionnaire was designed to address the research objectives related to the need analysis for adopting crystallography in the chemistry education curriculum in Nigeria. It comprised two sections:

1) Section A collected demographic information about the respondents.
2) Section B contained 12 questions organized into three clusters to address specific research questions.

The clusters were designed using a three-point Likert rating scale:

- Agree (A) = 1
- Undecided (U) = 2
- Disagree (D) = 3
- Cluster A focused on the importance of crystallography education in chemistry.
- Cluster B examined the readiness of the Nigerian education system for adopting crystallography education.
- Cluster C identified challenges that could hinder its adoption.

The questionnaires were printed and distributed to respondents, who were allowed time to complete and return them to the researchers. Immediate retrieval of the completed questionnaires minimized the risk of loss.

E. Reliability and Validation of the Instrument

To ensure reliability, the questionnaire was pretested on 20 respondents outside the sample population. Reliability was assessed using Cronbach's Alpha analysis, yielding a value of 0.87. This indicated high reliability, ensuring that the data collected would consistently address the research objectives under similar conditions.

F. Data Analysis

The collected data were analyzed using descriptive statistics and a one-sample t-test at a 0.05 level of significance, with the aid of Statistical Package for Social Sciences (SPSS), version 23.0. Paired-sample t-tests were employed to test hypotheses and verify if the mean differences between paired observations were significantly different from zero.

The mean scores were used to answer the research questions. For decision-making, a criterion mean of 1.50 was adopted. Items with a mean score of 1.50 or higher were considered accepted, while those below 1.50 were rejected.

III. RESULTS AND DISCUSSION

A. Descriptive Analysis of Demographic Variables

Table 3: Percentage Analysis Showing Demographic Variables

Variable	Group	F	%
Gender	(a) Male	70	40
	(b) Female	105	60

Table 3 above presents the frequency distribution of the various gender employed in this study. From the table, it was observed that 40% of the respondents were male students while 60% of them were female students respectively.

B. Descriptive Analysis of Research Questions

The three questions earlier raised in the study were answered descriptively.

1) Research Question 1: Is there any importance of crystallography education in the study of chemistry in Nigeria?

Table 4: Mean Analysis Showing the importance of crystallography in the study of Chemistry in Nigeria.

S/N	Statement	Level of Agreement			Mean	Decision
		A	U	D		
1	Crystallography can be used as a tool for teaching general chemistry concepts	105	40	30	1.5714	Agreed
2	The Crystallography has contributed groundbreaking achievements in elucidating the structure matter at or near the atomic level details, from the simplest inorganic salts to functional complexes or Proteins	125	25	25	1.4286	Disagreed
3	The advent of Crystallography helps in the reduction of the use of geometry to measure the angles of crystal.	85	75	15	1.6000	Agreed
	Grand Mean				1.5333	Agreed

Table 4 above presents the importance of crystallography in the study of Chemistry in Nigeria. From the table, it could be observed that mean scores of 1.5714 and 1.6000 agreed with items 1 and 3 respectively whereas the mean score of 1.4286 disagreed with item 2. With the grand mean of 1.5333, it was observed that most of the respondents agreed that there is an importance of crystallography education in the study of chemistry in Nigeria. This could be further explained in Figure 1 below.

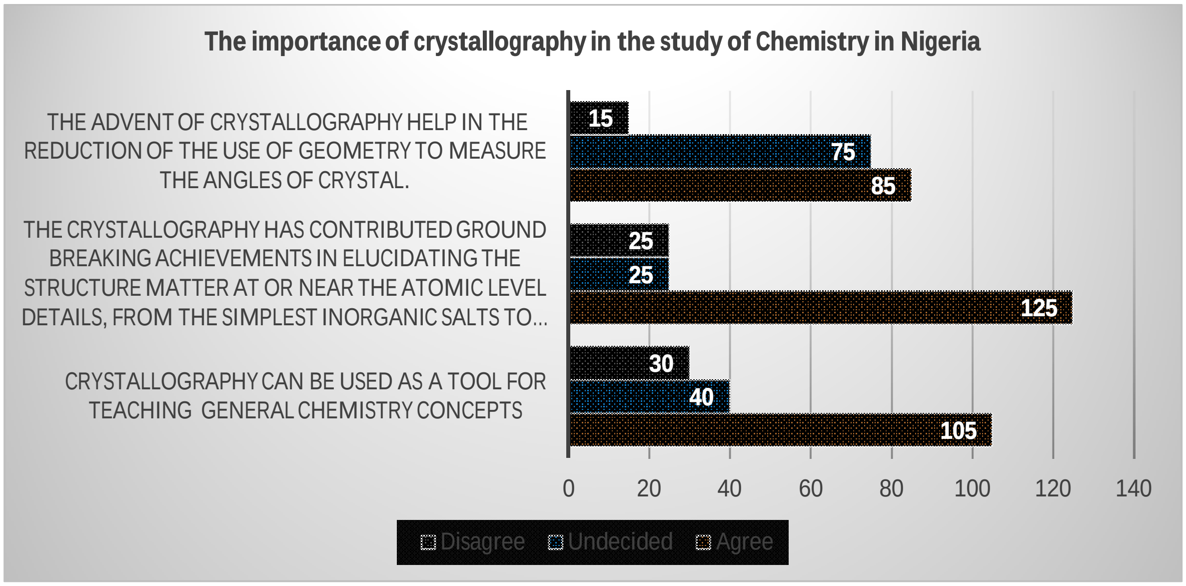


Figure 1: The Importance of Crystallography in the study of Chemistry in Nigeria

This observation supports the views of Rosado-Flores (2020) and Musil, *et al.* (2018) where the scholar noted crystallography establishes the new material's 'fingerprint' that could be used to prove that the new substance is unique when applying for a patent.

2) *Research Question 2:* What is the extent of readiness of Nigerian education system in adopting crystallography education?

Table 5 Mean Analysis Showing the extent of readiness of Nigerian education system in adopting crystallography education.

S/N	Statement	Level of Agreement			Mean	Decision
		A	U	D		
1	The Nigerian education system are ready to include Crystallography to undergraduates students as part of a core chemistry curriculum	85	75	15	1.6000	Agreed
2	Crystallography to secondary school children and non-science majors will be a welcome development.	80	70	25	1.6857	Agreed
3	The institutions in Nigeria have all it takes to inculcate and carry out crystallography in Chemistry education curriculum	58	59	58	2.000	Agreed
	Grand Mean				1.7619	Agreed

Analysis from Table 5 above explains the extent of readiness of Nigerian education system in adopting crystallography education. From the Table, it could be observed that the mean scores of 1.6000, 1.6857 and 2.000 agreed with items 1, 2 and 3 respectively. With the grand mean of 1.7619, it was observed that there is significant readiness of Nigerian education system in adopting crystallography education. This could be further explained in Figure 2 below.

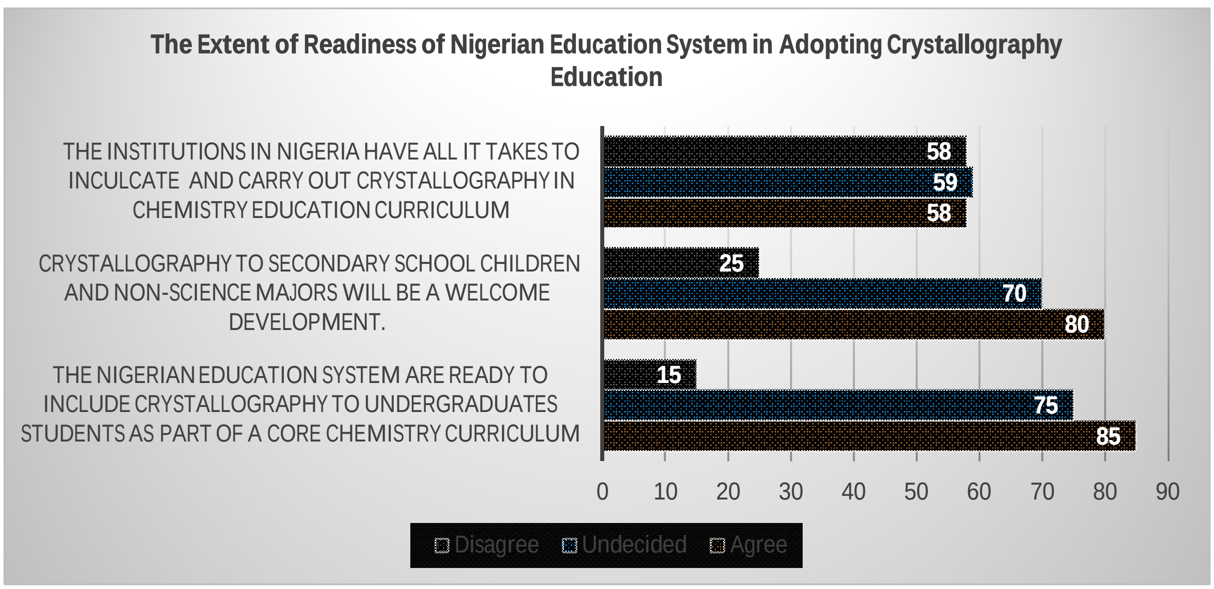


Figure 2: The Extent of Readiness of Nigerian Education System in Adopting Crystallography Education

This is in support of the views of Ezeugbora and Nwachukwu, (2018) where the scholars informed that the Nigeria educational sector is ever ready in adopting any changes or innovation that will grow the sector. To the study, the emergence of information and communication technologies (ICTs) and the ubiquitous connectivity of internet and networks improve man's ingenuity and opportunities given that societies consciously depend on real-time information to be proactive and to discount the effects of environmental changes. On the contrary, the outcome of this study contradicts the views of Odegbesan, *et al.* (2019) and Aboderin (2015) where the scholars explained that Nigeria as a country is yet to begin the discussions to adopt crystallography education in the Nigerian educational system. According to the scholars, the Nigerian educational system has no kind of preparation for the adoption of crystallography education, looking at the current state of the education and the lack of support from the necessary authorities in achieving the desired goal.

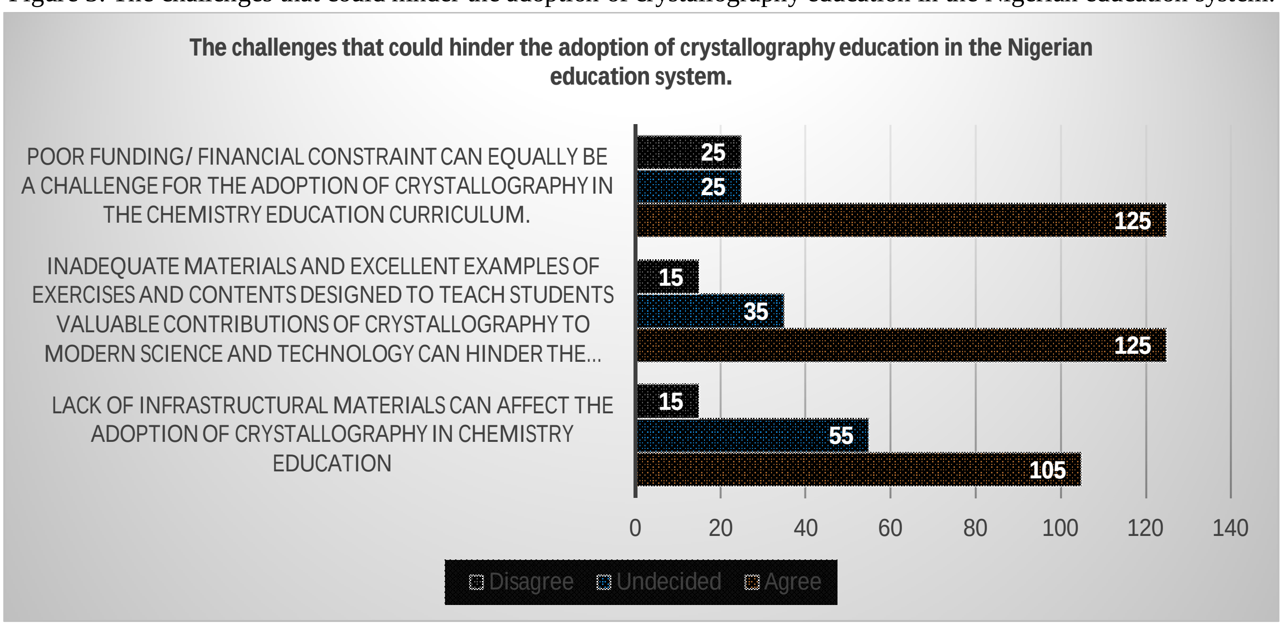
3) *Research Question 3:* Are there challenges that could hinder the adoption of crystallography education in the Nigerian education system?

Table 6: Mean Analysis Showing the challenges that could hinder the adoption of crystallography education in the Nigerian education system.

S/N	Statement	Level of Agreement			Mean	Decision
		A	U	D		
1	Lack of infrastructural materials can affect the adoption of crystallography in Chemistry education	105	55	15	1.4857	Disagreed
2	inadequate materials and excellent examples of exercises and contents designed to teach students valuable contributions of crystallography to modern science and technology can hinder the adoption of crystallography in Chemistry education	125	35	15	1.3714	Disagreed
3	Poor funding/ financial constraint can equally be a challenge for the adoption of crystallography in the Chemistry education curriculum.	125	25	25	1.4286	Disagreed
	Grand Mean				1.4286	Disagreed

Table 6 above presents the mean analysis showing the challenges that could hinder the adoption of crystallography education in the Nigerian education system. From the said Table, it could be observed that the mean scores of 1.4857, 1.3714 and 1.4286 were in disagreement with items 1, 2 and 3 respectively. The grand mean of 1.4286 indicated that most of the respondents disagreed that there are challenges that could hinder the adoption of crystallography education in the Nigerian education system. This could be further explained in Figure 3 below.

Figure 3: The challenges that could hinder the adoption of crystallography education in the Nigerian education system.



This study is backed up by the views of Tsaparlis (2015) where the scholar noted that the teaching and learning science concepts in high school, instructional methodology; secondary chemistry curricula; structural concepts; higher-order cognitive skills (HOCS); problem solving in science, and chemistry in particular; and, relevant chemistry education as the challenges confronting a teacher of chemistry, thus, recommending the need for crystallography education in schools.

C. Hypothesis Testing

This section discusses the research hypotheses which were formulated earlier in chapter one of this study. The hypotheses were tested with the aid of One-Sample t-test. These hypotheses are brought forward for testing.

H01: There is no importance of crystallography education in the study of chemistry in Nigeria.

H02: There is no significant readiness of Nigerian education system in adopting crystallography education.

H03: There are no challenges that could hinder the adoption of crystallography education in the Nigerian education system.

1) Decision Rule

If the probability value of the t-calculated is less than or equal to the 5% level of significance or confidence interval, you reject the null hypothesis to accept the alternative that the analysis is significant statistically. But if the probability value of the t-calculated is greater than the 5% level of significance or confidence interval, you reject the alternative hypothesis to accept the null that the analysis is not significant statistically.

That is to say,

If Pr(t-test) <= 0.05,

Accept H_1 thereby Rejecting H_0

But if Pr(t-test) > 0.05,

Accept H_0 thereby Rejecting H_1.

2) First Hypothesis

H_{01}: There is no importance of crystallography education in the study of chemistry in Nigeria.

H_{11}: There is importance of crystallography education in the study of chemistry in Nigeria.

Table 7 – One-Sample Test of Hypothesis One

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
The importance of crystallography education in the study of chemistry in Nigeria.	27.038	174	.000	1.57143	1.4567	1.6861

Table 7 above shows the t-test analysis of the importance of crystallography education in the study of chemistry in Nigeria. It is observed that with a t-probability value of 0.000 which is less than the 5% level of significance, we accept the alternative hypothesis that the analysis is significant statistically.

With this, the researcher concludes that there is importance of crystallography education in the study of chemistry in Nigeria.

3) Second Hypothesis

H_{02}: There is no significant readiness of Nigerian education system in adopting crystallography education.

H_{12}: There is a significant readiness of Nigerian education system in adopting crystallography education.

Table 8 – One-Sample Test of Hypothesis Two

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Extent of readiness of Nigerian education system in adopting crystallography education.	32.904	174	.000	1.60000	1.5040	1.6960

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Table 8 above shows the t-test analysis of the extent of readiness of Nigerian education system in adopting crystallography education. It is observed that with a t-probability value of 0.000 which is less than the 5% level of significance, we accept the alternative hypothesis that the analysis is significant statistically.
With this, the researcher concludes that there is a significant readiness of Nigerian education system in adopting crystallography education.

4) Third Hypothesis

H_{03}: There are no challenges that could hinder the adoption of crystallography education in the Nigerian education system.
H_{13}: There are challenges that could hinder the adoption of crystallography education in the Nigerian education system.

Table 9 – One-Sample Test of Hypothesis Three

One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Challenges that could hinder the adoption of crystallography education in the Nigerian education system	30.196	174	.000	1.48571	1.3886	1.5828

Table 9 above shows the t-test analysis of the Challenges that could hinder the adoption of crystallography education in the Nigerian education system. It is observed that with a t-probability value of 0.000 which is less than the 5% level of significance, we accept the alternative hypothesis that the analysis is significant statistically.
With this, the researcher concludes that there are challenges that could hinder the adoption of crystallography education in the Nigerian education system.

D. Discussion of Findings

This section in particular is concerned with those findings of this study. After the hypotheses were tested, the researcher made the findings below:

1) Objective One: Evaluating the importance of crystallography education in the study of chemistry.

In evaluating the importance of crystallography education in the study of chemistry, the researcher discovered that there is importance of crystallography education in the study of chemistry in Nigeria. The opinion was made due to the result of the hypotheses testing realized which was a guide to the researcher in making the decision.
This finding is in tune with the findings of Malbrecht, *et al.* (2016) where the scholars noted that crystallography can be used as a tool for teaching general chemistry concepts as well as general research techniques without ever having a student determine a crystal structure. To the authours, it may not be the most familiar branch of science to everyone, but crystallography is one of the most important techniques in helping to understand the world around us. Crystallographers can work out the atomic structure of almost anything and they use this knowledge to answer why things behave the way they do.

2) Objective Two: Examining the readiness of Nigerian education system in adopting crystallography education.

In order to examine the extent of readiness of Nigerian education system in adopting crystallography education, the researcher found that there is a significant readiness of Nigerian education system in adopting crystallography education. This suggestion was made based on the result of the hypotheses testing done by the researcher which helped in making the decision.
This finding relates to the views of Mbachu and Hamilton-Ekeke (2013) where the scholars explained that the process of educating is metamorphosing and one of the greatest impetus is the impact of information and communication technology right from the 19th century when the first set of technologies were introduced. According to Kennah (2016), the usefulness of invention in influencing instructional strategy in schools could foster the development of educational media resources, thereby, influencing learning.

3) *Objective Three: Appraising the challenges that could hinder the adoption of crystallography education in Nigerian education system*

In appraising the challenges that could hinder the adoption of crystallography education in Nigerian education system, the researcher's observation was that there are challenges that could hinder the adoption of crystallography education in the Nigerian education system as shown in the result of the hypothesis testing carried out by the researcher.

The researcher's finding is in relationship with the views of Sozbilir, *et al.* (2010). To Sozbilir, *et al.* (2010), with every leap in technology a new set of challenges are quickly found. There have been several step-changes for service crystallography, notably the introduction of automated diffractometers in the 1960's and 70's and the dramatic increase in computing accessibility and power in the last couple of decades. Sozbilir, *et al.* (2010) added that many areas of modern research are producing increasing numbers of poor quality crystals, due to inherent characteristics relating to their chemistry and this has implications for the collection, processing and work-up of data and the quality of the final result. Accordingly, certain classes of compounds of current interest e.g. metal–organic frameworks or biologically relevant supramolecular complexes, tend to form predominantly small or weakly scattering crystals. Modern synthetic procedures are capable of producing large and sophisticated systems – much like working with protein structures – and these systems generally have a high degree of conformational flexibility, leading to disorder and lower resolution datasets.

IV. CONCLUSION

What many nations like Nigeria need now is a functional chemistry education that will assist in national development. Chemistry education has been identified to be one of the major bedrocks for the transformation of our national economy, thus, the need for the Nigeria educational sector to adopt any changes or innovation that will grow the sector.

After evaluating the need for changes in the Nigerian chemistry education curriculum by incorporating crystallography education, this study reached the following conclusions:

1) Crystallography education plays a crucial role in enhancing the study of chemistry in Nigeria.
2) The Nigerian education system demonstrates significant readiness to adopt crystallography education.
3) Several challenges exist that could impede the adoption of crystallography education in the Nigerian education system.

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