

Comparative Evaluation of Indigenous, English and Bilingual Instruction in an Indigenous Knowledge-Integrated Blended Physical-Virtual Chemistry Laboratory: Effects on Students' Practical Skills and Conceptual Understanding in South-East Nigeria

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ABSTRACT

Language in chemistry education helps students relate macroscopic and microscopic aspects of their understanding of chemistry, apply chemistry concepts to laboratory work, decipher the relation between chemistry and other disciplines, and interpret chemistry terms. Because English has recently been endorsed as the official instructional language of all levels of education in Nigeria, the researcher compared the effects of English-only, Igbo-only and strategically combines Igbo and English teachings on the integration of indigenous knowledge in a chemically-based science laboratory in Nigeria. The researcher collected data from 120 senior secondary school II students from 10 public, co-educational schools each from Abia, Anambra, Ebonyi, Enugu and Imo States. The instructional methods compared were integrated in a science laboratory which emphasises the science of chemistry using different, contextually relatable, examples to students' environments. Conceptual understanding and practical skills were analysed with pre-test-adjusted ANCOVA using school cluster-robust adjustment. Comparisons were made between Holm-adjusted means. Differences at baseline were no significant. Language used for instruction was significantly related to both conceptual understanding and practical skills. For conceptual understanding, language used for instruction accounted for 32.3% of the variance, ($F(2, 350) = 83.40, p < .001$). For practical skills, language used for instruction accounted for 16.8% of the variance ($F(2, 350) = 35.29, p < .001$). Conceptual means were 62.93 for English, 68.67 for Igbo and 74.29 for bilingual. The means for practical skills were 62.04 for English, 65.01 for Igbo and 69.87 for bilingual. All comparisons were significant after Holm-adjustment, including the comparison of practical skills between Igbo and English ($p = .025$). The results illustrate that in culturally relevant ways, Igbo offers contexts for sense making. The study offers proof that in South East Nigeria, bilingual Chemistry Education integrates culturally relevant knowledge and is complementary to English Chemistry Education.

KEYWORDS

Chemistry education, Igbo language, bilingual instruction, translanguaging, indigenous knowledge, blended laboratory, virtual laboratory, practical skills, conceptual understanding, south-East Nigeria

I. INTRODUCTION

Learning chemistry means relying on and skilfully integrating language, observation, measurement, and theory. Chemistry is as linguistic as it is practical. To be successful in a chemistry classroom and laboratory, the learner must be able to connect the dots, so to speak, between observed phenomena and the theoretical. This requires both representation (i.e. drawing conceptualised or symbolic representations) and linguistics. Hence, the learning and practising of chemistry is as linguistic as it is practical. Although, in recent times, science has been taught predominantly in English, as is the case in Nigerian classrooms, the indigenous languages of the learners continue to dominate the communication of everyday science.

South-East Nigeria is an area where we can study the role that language plays in science education. The region comprises Abia, Anambra, Ebonyi, Enugu and Imo States. The Igbo language is present in all areas of people's lives, and English is present in textbooks, formal lessons and testing. Students are assessed in English, despite experience in various scientific phenomena and events including fermentation and soap and palm oil production. These students may need to use English to interpret the phenomena in chemical terms. This may require an individual to first define an event using the language of science and then put it into chemical context. It is possible to design instruction in South-East Nigeria in a manner that facilitates learning of chemistry. Igboanugo (2023) reported that chemistry students in SSII in Anambra State learned chemistry through guided inquiry, and teacher education and experience played a major role. This research explores this pedagogical issue by considering the role of English and other languages of instruction.

While more recent Nigerian research studies on the teaching of the mother tongue are still scanty and lack adequate definitiveness, a few findings have been compiled. Chukelu and Nkok (2024) revealed that pupils in Imo State performing basic science in Igbo recorded better performances than their counterparts performing in English. In addition, Bosah, Okika and Anozie (2025) reported a similar positive trend of performing basic science in the mother tongue (Igbo) in Awka South Local Government Area of Anambra State. Also at the senior secondary level, it was reported by Oso (2024) that the use of learners' mother tongue in combination with English, had a positive impact on learners' academic performance in English Language and Integrated Science. Similarly, Salihu et al. (2025) reported that the use of Hausa and other local languages as complements to English in teaching Chemistry, positively impacted on students' performance in chemistry process skills. However, as Obiakor (2024) observed, (in some contexts) teaching and learning English improved students' scientific literacy and made positive impact on other areas of learners' academic performances. Therefore, the salient issue for educational analysis, is not which language is generally preferable, but in what situations are certain language combinations that enhance learners' academic performances and break disciplinary barriers.

Bilingualism and translanguaging approaches provide educators with an alternative to reducing their practice to English and indigenous languages. An integral part of the translanguaging perspective is the consideration of learners' linguistic repertoires in an integrated manner, as opposed to considering them as distinct linguistic compartments. Kiramba and Charamba (2023) provide evidence on the use of home languages to enhance learning in chemistry and Physics by focusing on epistemic access. The use of translanguaging in the construction of scientific explanations is also demonstrated in Charamba (2023). He and Zhou (2024) provide evidence on the use of pedagogical

translanguaging to enrich science teaching in English-medium classrooms. Trends in research suggest that translating in Science and Mathematics education is the most widely researched area, with a good deal of variability in the methods used. Therefore, bilingual teaching of Chemistry should be viewed as a deliberate integration of both English and Igbo. For example, Eliciting learners' prior knowledge and experience to construct causal relationships in learning and indigenous knowledge, and integrating Chemistry concepts and terminology with the help of English may be helpful.

Language also interacts with the format of laboratory experience. While a virtual laboratory may make certain processes visible, be repeatable, and reduce the cost and safety concerns of performing an experiment, it cannot fully replicate the experience of working with and manipulating equipment with respect to the uncertainty involved with real materials. In a systematic review of chemistry simulations, Palacios Ortega, Pascual López, and Moreno Mediavilla (2024) noted that, from an educational standpoint, simulations become more effective when they are integrated within an overall instructional strategy, rather than used as individual, standalone activities. In Nigeria, the use of virtual laboratories has been associated with several positive effects, including improved achievement in laboratory classes and practical performance. The results support the use of a blended (virtual and traditional) approach to laboratory work, with the virtual activities used to supplement and reinforce practical work. If a blended approach is used with all language groups, the design can be used to investigate the effects of language rather than making similar conclusions based on the modality of laboratory activities.

Another consideration is cultural relevance. Indigenous knowledge incorporation does not mean that we dispense with chemistry and other disciplines and resort to untested claims. In chemistry, for instance, various hypotheses, observations and explanations can be drawn from community practices. Chibuye and Singh (2024) and Simasiku and Ngcoza (2024), respectively, provide valuable insights on the integration of ethnochemistry and indigenous knowledge in teaching secondary chemistry, and in using indigenous knowledge to conceptualise acids and bases. There is a growing body of research that highlights using locally relevant cases to illustrate principles of science, technology and math. In doing so, a pathway is provided for mediating tensions that may exist between community knowledge and scientific knowledge. Using the case of South-East Nigeria, it is possible to integrate indigenous knowledge in a science laboratory and use it to illustrate similarities and differences in teaching methodology in the three language modes (Igbo, English and Bilingual).

The interdisciplinary nature of these literatures clearly identifies what is lacking. Numerous studies have been conducted regarding different indigenous sciences, especially chemistry, and associated pedagogies, learning, and teaching practices. The same is also true for laboratory learning. However, relatively few studies have fixed the content and the modality of the laboratory sessions and varied only the language in which identical sequences of chemistry teaching integrate other indigenous knowledge's. This is particularly true of research from South-East Nigeria and research that distinguishes conceptual understanding from hands-on, measured, and directly tested practical skills. Conceptual understanding is likely to be language-bound, especially where teaching requires representation and where teaching and learning activities concentrate on discourse. Manipulation of apparatus, by comparison, is largely language-independent. An experimental design varying the language of instruction in chemistry and integrating other indigenous knowledge, while holding

content and modality of teaching and learning fixed, may offer more insight into conceptual and practical outcomes.

The study used an equivalence design to compare English-only, Igbo-only, and bilingual Igbo-English instructions within a blended physical virtual chemistry laboratory integrating indigenous knowledge, for learners of SSII in schools within the South East Nigeria. The study tested two major null hypotheses. First, the study postulated that there will be no significant differences in the post-intervention conceptual understanding of the participants in the three language conditions, after accounting for pre-test and contextual covariates. Second, the study hypothesised that there will be no significant differences in the post-intervention practical skills of participants in the three language conditions after accounting for the same covariates. Lastly, the study conducted a set of planned comparisons to examine English-Igbo, bilingual-English, and bilingual-Igbo conditions. The author performed all the analyses on the main research field sample collected from the sampled schools, and examined whether the post-intervention findings remain significant after accounting for pre-test and contextual covariates.

II. LITERATURE REVIEW

A. Language of instruction and scientific meaning-making

Language performs multiple epistemic functions in a science classroom. It labels the entities, expresses the steps of procedures, facilitates discussion and in conjunction with other language, expresses and interprets evidence. It expresses and structures scientific argumentation and causal relations. More advanced functions may also be part of language in the science classroom. Chemistry tends to require the highest level of function coordination among all branches of science. Students have to connect everyday language with specialized terminology and other forms of representation, i.e. musical notation and symbols. A student may express that an ash-derived filtrate is "slippery", but she may also need to explain it as the presence of alkalinity and hydroxide ions and as the result of a neutralization and/or saponification. A student may know a number of descriptions of an observation, but explaining an observation as the result of the processes of science may prove to be challenging. If instruction is only in an unfamiliar academic language, students have to split their attention to figure out what the language means and how it is connected to the science. Since multiple academic languages are present in science, scholarship in science and multilingualism stresses that the use of several academic languages does not necessarily enhance students' command of science. González-Howard et al. (2023) say that the ideologies toward language affect what students do in science. Grappin et al. (2023) say that changing education so that the languages of the community are used in science education is legalizing the use of those languages in science.

Research shows that movement across languages can help with disciplinary learning. However, this is only effective if the movement is done for a particular reason in the classroom. For instance, in Grade 10 Chemistry, Kiramba and Charamba (2023), noted the role of the home language for students in accessing scientific ideas. This was viewed as a positive addition to scientific explanations instead of a departure from scientific methodology. In another study, Charamba (2023), reported the positive role of translanguaging in the development of scientific explanations. He and Zhou (2024), reported

the positive role of the integration of multiple languages and multiple means of representation in teaching science. The suggestions from these studies can be adopted in South East Nigeria. It is not enough to ascertain if students of this region can communicate in English; it is important to identify if teachers can assist students articulate their ideas in English, interrogate observed phenomenon, and connect ideas to scientific concepts. Bilingual teaching may assist students of this region to develop scientific ideas and communicate them in English.

Approaches that make use of the full linguistic repertoire of individuals and communities, known as translanguaging, are often seen as positive and effective. However, translanguaging should not be seen as universally or naturally effective. It has been noted that when translanguaging is discussed in K-12 science education, there is little consensus regarding how it is defined and implemented. Similar comments have been made about research in the field of STEM. Different ways of interpreting a given research method or educational practice can lead to a range of outcomes and interpretations. Not all researchers, for example, may draw the same conclusion from a pedagogically designed bilingual practice. Those involved in research related to the classroom should take a similar position. In this study, the researchers sought to test the effects of pedagogical translanguaging in a range of conditions. Fidelity was determined by how instructional functions were defined, not whether translation occurred.

Table 1. Selected recent studies (2023-2026) positioning the present research gap

Study	Context	Principal contribution	Remaining gap
Kiramba & Charamba (2023)	Multilingual Grade 10 chemistry, South Africa	Translanguaging/home-language use and epistemic access	Supports chemistry-specific bilingual meaning-making; no Igbo comparison
Chukelu & Nkok (2024)	Basic science, Imo State, Nigeria	Igbo mother-tongue instruction outperformed English	Younger learners; not chemistry laboratory
Oso (2024)	SSII science classrooms, Nigeria	English complemented by mother tongue supported understanding/performance	Not an experimental three-language chemistry design
Obiakor (2024)	National Nigerian primary data	English sometimes outperformed indigenous-language instruction in literacy	Shows effects are context- and implementation-dependent
Chibuye & Singh (2024)	Secondary chemistry, Zambia	Ethnochemistry/local knowledge as curriculum resource	Documents context, not language-condition effects
Palacios Ortega et al. (2024)	Systematic review, secondary chemistry	Virtual simulations work best within purposeful methodology	Supports virtual component; not indigenous-language focused
Bosah et al. (2025)	Basic science, Anambra State	Positive relationship between mother tongue and achievement	Primary/basic level and correlational design
Salihu et al. (2025)	Secondary chemistry practical, Niger State	Hausa practical module supported science-process skills	Different language/region; module rather than

			three-group comparison
Eze et al. (2025)	Secondary chemistry, Nigeria	Culturally responsive pedagogy using local resources improved achievement	Does not isolate instructional language
Hou et al. (2025)	Global K-12 science systematic review	Translanguaging supports inclusive science meaning-making; methods heterogeneous	Calls for stronger outcome-focused designs
Cheung & Ng (2026)	STEM systematic review	Translanguaging research concentrated in science/mathematics	Highlights need for disciplinary-learning outcomes
Konyefa (2026)	SSII acid-base titration, Bayelsa State	Offline virtual simulation improved practical skills	Supports virtual rehearsal; not language-focused

Source: Compiled by the author from recent peer-reviewed literature reviewed in this paper.

B. Indigenous-language science instruction in Nigeria and the Igbo context

Although Nigeria is a multilingual country, Obiakor (2024) asserted that the presence of multiple languages did complicate Nigeria's language-in-education policies. This research demonstrates how policies concerning mother-tongue education were sometimes implemented unevenly. The research suggests that in contexts where learners received science education in English, several challenges arose, and there was a general lack of instructional resources, and sometimes, the teachers were not adequately trained. In the contexts where science education was provided in the mother-tongue and English, combined, learners achieved a better understanding of science. The research demonstrated a more reasoned case for the implementation of science education in Nigeria using a combined approach of English and one or more of the indigenous Nigerian languages.

C. National language-in-education policy and the English-medium debate in Nigeria

Recently Nigeria's Language in Education policy changed. In 2022, the Federal government through a National policy on language stated that languages of education in schools should be the languages of the communities or the mother tongue in the early years. In November 2025, The Federal government (through the resolutions of the 69th National Council on Education) changed the policy, reinstating English as the medium of education at all levels, and abolishing the policy of mother tongue as medium of education. The accompanying Policy on Language (Inclusive Language Policy) stated that Nigerian languages will continue to be taught and will be a part of school's activities. However, for purposes of instruction, English was made the medium of instruction.

Among the senior secondary school chemistry courses, English is the medium of instruction, school textbooks and national examinations. Because of the above policies, the mother tongue of students is not the medium of their education and instruction in senior secondary schools. English can provide instructional and learning materials for senior secondary students as well as serve to integrate school students across Nigeria.

The other side provides a thorough argument as well. The Nigerian Academy of Education (2025) took issue with the widespread removal of schooling in local languages and presented evidence that students' first language may be appropriately used to bolster students' understanding and maintain students' cultural values and cognitive learning, as long as it is supplemented by learning materials and/or teaching in English. This position is supported by research focused on Science Education and the role of first language/other local languages in providing students with initial understanding of Science concepts and processes. In Chemistry Education, researchers have similarly suggested the integration of other local languages, including Igbo, to support Science teaching and learning. It is, however, advisable that such teaching, learning and integrating be done in tandem with English, given that, policy wise, English is the preferred medium of instruction. The three-condition scenario takes into account the primacy of English and the consequences of allowing Igbo and/or English to be used in Science teaching.

Particularly relevant evidence comes from South-East Nigeria. Chukelu and Nkok (2024) showed that for lower-basic pupils in Nwangele Local Government Area, Imo State, instruction in Igbo promotes the achievement of basic science. Also, Bosah, Okika, and Anozie (2025) demonstrated that for pupils in Awka South Local Government Area, Anambra State, instruction in mother-tongue (Igbo) facilitates achievement in basic science. As learned earlier, the focus of the various studies (particularly those dealing with learning of senior secondary chemistry) is on the language of instruction, learning materials and the scientific discourse of chemistry. Thus, when compared with these, the other studies focus on basic/elementary school, and the scientific discourse of chemistry is not so different. However, the various studies show that Igbo is a language of scientific discourse and may be legally used in teaching senior secondary chemistry.

This phenomenon presents an opportunity to understand the strengths of strategically bilingual instruction, compared to both monolingual options. Instruction in English, and only English, is directly linked to textbooks, English-translated national assessment exams, and international scientific terminology. This, however, limits the ways in which learners can explain concepts. Instruction in Igbo is aligned to culture, and may help eliminate barriers to participation. Translating terms in Igbo to English may, however, become limiting. Strategically bilingual instruction allows the assignment of differential but concurrent functions to the two languages. For example, in one instance, learners may explain gas evolution during fermentation in Igbo, and compare that with community understanding of fermentation. The explanation may then be articulated in English by alluding to the terminal products of anaerobic respiration and evolving carbon dioxide. It must be emphasised that the aim of this instruction is not to arrive at English and Igbo parallel explanations of chemical concepts, but to arrive at a unified understanding of chemical concepts using both languages.

D. Bilingualism, translanguaging and chemistry-specific disciplinary language

Integrating chemistry with other disciplines requires the use of specialized language. The language may be bilingual or multilingual. An Igbo-English teacher of chemistry may use English terms and symbols for specialization. However, she may need to use Igbo to help learners make connections with their contextual experiences and/or to link scientific reasoning to prior knowledge. As learners have previous contextual understandings of a system, one can address reasoning in chemistry through research on meaning embedded

in connections using words, symbols, or representations. The understanding has been shown to promote the agency of learners to engage in disciplinary reasoning.

There is no need for a translanguaging approach to terminology in teaching chemistry to rely on forced translations. This can be accomplished using learners' prior contextualized knowledge of substances and processes to formalise reasoning. Some examples of such prior knowledge can be found with mmiri (water), nnu (salt), ncha (soap), mmanụ nkwụ (palm oil), mmanya nkwụ (palm wine), ntụ (ash), ígwè (iron/metal), nchara ígwè (rust on iron) and ọkụ (fire/heat).

Table 2. Illustrative Igbo-English lexical anchors for chemistry instruction

Igbo expression	English gloss	Illustrative chemistry relevance
Mmiri	Water	Solvent, solutions, heating/cooling, aqueous reactions
Nnu	Salt	Ionic compounds, solubility and crystallisation
Ncha	Soap	Saponification, alkalinity and surfactant behaviour
Mmanụ nkwụ	Palm oil	Lipids, density, separation and soap production
Mmanya nkwụ	Palm wine	Fermentation, gas evolution, acidity and reaction conditions
Ntụ	Ash / wood ash	Alkaline filtrates, pH, acids and bases
Ígwè	Iron / metal	Metals, reactivity and redox processes
Nchara ígwè	Rust on iron	Oxidation and corrosion
Ọkụ	Fire / heat	Thermal change, combustion and reaction-rate discussion

Note: These are familiar lexical anchors rather than a claim that all technical chemistry terms possess standardised one-to-one Igbo equivalents. Classroom use should be sensitive to dialect variation and should retain internationally recognised chemical symbols and nomenclature.

Due to the potential for procedural mistakes due to miscommunication, bilingual education may be particularly useful during laboratory work. For example, some students may have learned through bilingual education how to rinse a burette or how to read the meniscus. Other students may have learned through this education the correct procedure for adding indicator solution to the delivery system. While Igbo language may assist in communicating the rationale for a procedure or the correct order of a procedure, English may assist in retaining key terminology. Salihu et al. (2025) noted that developing practical work in various languages may not be a challenge. This may indicate that the learning of technical procedures for laboratory work may not always be linked to learning English. However, in Salihu et al.'s (2025) study, a bilingual approach may strengthen the link to the formal assessment system more than a monolingual Igbo approach. This, however, is contingent on technical terminology not be removed, and the rationale for procedures not be over-simplified.

There are social consequences of bilingual teaching. There is the potential for students to express uncertainty and engage in discourse that includes negotiating and constructing meaning. Often, the language used to describe uncertainty is language that best facilitates reason-giving so that research participants can interrogate, challenge and change their

ideas. There is an evident monolingual English norm that produces “quiet” classrooms. Such classrooms are a disguised cover for a lack of understanding. However, a classroom that uses only the research participants’ language can imply to the participants that, in the process of learning and acquiring the vocabulary of formal science and other school subjects, English is of primary importance and the other school subjects are secondary. In classrooms where scientific concepts are taught using different concepts in both English and the participants’ language, there is no such implication and classroom interactions are less controlled and restricted.

E. Indigenous knowledge integration and ethno chemistry

Language effects are most powerful when culturally appropriate content is meaningfully integrated into instructional materials. Transformations of matter have always fascinated researchers. Documented practices include dyeing, fermentations, food preservations and extractions as well as metallurgical extraction and soap making practices. Elsewhere, Chibuye and Singh (2024) describe local chemistry and teaching practices from Zambia. In South-east Nigeria, it is similarly possible to find local chemistry and technologies within foreseeable practices and indigenous knowledge that is appropriate to construct relevant teaching and learning units. Teaching and learning units can be constructed from locally known practices and technologies within the environment to teach students the concepts of engineering and science. Emphasis should be placed on critical thinking to generate relevant and focused questions. It is the responsibility of the chemistry educator to integrate sufficient chemistry content to address the questions students have formulated.

While integrating indigenous knowledge is encouraged, recent studies warn against tokenism. Simasiku and Ngcoza (2024) studied the role of indigenous knowledge in the teaching and learning of acids and bases and identified the challenges brought about by the teachers’ knowledge and the curriculum. In the field of chemistry education, Mlotshwa and Tsakeni (2024) identify challenges pertaining to culturally relevant practices and beliefs that are beyond the control of the teachers and provide exemplary practices where integrated indigenous knowledge helped create realistic and practical learning scenarios. Ogegbo and Ramnarain (2024) also identified challenges in the field of science education where integrating indigenous knowledge systems (IKS) require a deliberate teacher action and not an overly generalised teaching. Tawanda and Mudau (2026) extend previous research where they conceptualise indigenous Chemistry knowledge and Western Chemistry knowledge as two distinctive yet complementary areas of Chemistry. These studies encourage an interdisciplinary approach to Science education where practices of communities are regarded as science phenomena.

Research is accumulating relevant to the Nigerian context. For instance, Eze, Okere and Okorafor (2025) indicated the use of culturally responsive pedagogy to incorporate locally relevant resources and indigenous learning approaches had a positive influence on the achievement of secondary school learners in chemistry. A similar tendency was reported by Umahaba (2026) in the case of some pre-service science students, and an ethnosience approach in the case of secondary school chemistry students was reported by Jack and Famiwa (2026). It appears chemistry-learning approaches that incorporate culturally relevant contexts and materials work well. What was not addressed in any of these works was if using indigenous-language resources to set up laboratory sessions in chemistry would make a difference. It is important to address this gap, because using a relevant example in

a foreign linguistic framework may make little epistemic sense to the learner, when compared to using a similar example and a framework in the learner's native language.

The present study adopts a model of culturally-based boundary crossing for integration. Each experiment involves identifying a culturally-recognisable phenomenon or practice; generating student-generated explanations for it; rendering the phenomenon as a school-laboratory investigable question; making use of ICTs to model and/or describe science processes that are not directly observable; and ending with a formal explanation of the science involved. The three language variations differ in the nature of the verbal mediation provided. The same body of scientific knowledge is covered in all three versions. The structure of the variations minimises the chances of a particular group being provided with culturally-based examples that are of a richer nature than those provided to other groups. The variations therefore, allow a thorough test of the role that language plays in integrating indigenous knowledge and science teaching.

F. Blended physical-virtual laboratories and the distinction between knowing and doing

Acquiring the skills taught in laboratories involves both cognitive and psychomotor skills. It is inadequate to measure the attainment of either or both skills and report the aggregate as achievement. Virtual environments can depict processes at a level beyond the naked eye. They can also provide users with instant feedback and allow them to perform processes repeatedly. Thus, a virtual environment can improve learners' understanding of processes and scientific concepts. The use of virtual environments for the construction of chemistry concepts and skills has been found to improve chemistry achievement. Similarly, other studies conducted in Nigeria have found positive effects of virtual laboratory education on teaching and learning. Positive effects of virtual laboratory education were found to facilitate access and improve the chemistry achievement of students in poorly equipped schools.

There are inherent limitations of virtual labs in developing practical skills. There is a specific judgement that is embodied in clamping glassware, controlling stopcocks, and determining the location of a meniscus. While some experiments may lend themselves to virtual representation, our experience suggests that the unexpected, and often undesired, outcomes of many chemical experiments will not be adequately represented in virtual environments. Recent work from Nigeria is instructive. Offline virtual simulations, in this case of acid-base titrations, have been shown to build procedural skills. Other studies have shown the benefits of virtual labs in the instruction and learning of chemistry. Despite innovative instructional design and the benefits shown for virtual labs, it may be more advantageous to incorporate both virtual and traditional labs in chemical education. Virtual labs, in this regard, could be considered complementary rather than replacing traditional labs.

As the focus of this paper is language conditions, a blended model is most appropriate. A blended model provides the opportunity for students to engage with representations in various ways, including verbally and physically. With a blended model, students all have the opportunity to see the same virtual molecular animations, class apparatus and complete the same experiment. Any differences in students' outcomes can be attributed to differences in language mediation. It may also be the case, as predicted by the blended model, that language may affect students' conceptual understanding more than their practical understanding. This hypothesis will be tested in this paper by focusing on larger effects on conceptual understanding than practical skill.

G. Integrative framework and study expectation

The framework proposes three mechanisms. The first is linguistic accessibility. Igbo language can help reduce the gap between students' normal and educational logic. The second is disciplinary bridge. The English language provides students with direct access to the texts' technical expressions and various teachings. The third is representational bridge. The integration of virtual and material representations in laboratory activities represents a means for students to link words to physical or virtual events. In this study, the focus is on disciplinary bridge and linguistic accessibility. In the absence of Igbo language, linguistic accessibility may remain inadequate. However, the presence of English, coupled with the cognitive efforts of students may serve to improve linguistic accessibility. In the presence of both English and Igbo languages, students have the opportunity to integrate what they have learned in diverse ways.

This model predicts the order of the groups rather than just any kind of difference. As far as conceptual understanding is concerned, the predicted ordered group means are bilingual instruction > Igbo only > English only. Concerning practical skills, I expect the same order but the gaps would be smaller because the groups rely on the same experiment apparatus and virtual labs. The model goes beyond a simple assertion that bilingualism is beneficial. It states the predicted order of group differences and the impact of different languages in each situation. This model justifies the use of different ANCOVA models, planned comparisons and estimates of effect sizes rather than relying on post-tests means.

III. METHOD

A. Research design and data source

The study employed a quasi-experimental design, that is, a three-group (Igbo only, English only, and bilingual Igbo-English) post-test and pre-test design. Data were collected from S.S. II (chemistry) students in public secondary schools in South-East Nigeria. Data collected were from students' achievement test scores prior to and after an instructional period of six weeks. Data were collected in a way that allowed the control of clustering due to the school, and in a way that supported adjustment for confounders. The intent was to collect the data needed to perform covariance-adjusted analysis on the three pedagogical conditions. The analysis performed on the data included estimation of group means and other statistical analysis.

B. Study setting, population and sampling procedure

The study was conducted in South-East Nigeria's Abia, Anambra, Ebonyi, Enugu, and Imo states. The study was conducted in public, co-educational, Senior Secondary II (SSII) Chemistry classes. SSII was chosen as it offers opportunities to build upon students' previous understanding of some basic concepts of chemistry, without being constrained by preparation for final external exams. The final sample consisted of 360 SSII students, comprising 30 schools, and six schools per state. Other things being equal, across the schools represented in each state, two schools were selected to represent each of the two language conditions. From each school, 12 students, representing the entire class, were sampled. Therefore, the total number of participants in each language condition was 120,

and the sample was sex-balanced. This sampling structure helped answer the language comparison and ensure the school representation was adequately sampled.

C. Intervention structure

The three study conditions all participated in a six-week integrated, indigenous knowledge-based blended, hands-on, virtual chemistry laboratory programme. The programme was designed in a stepwise manner with each step comprising of preparation, performance, and consolidation. Preparation involved completing a set of virtually sequenced activities to review the apparatus and procedures, familiarise with varying experiment parameters and visualise and manipulate representations of macromolecular structures and processes. Performance consisted of carrying out the planned laboratory activity, making and recording observations and measurements and practising laboratory safety and health procedures. Consolidation stage of the next repeat cycle of the programme was used to review the laboratory activity, explain and interpret any anomalous results, and relate observed macroscopic data and conclusions to symbolic and sub microscopic representations. Language and discourse of instruction were the major variables used to implement the treatment. All other elements of instruction were kept constant.

D. Language-condition protocols

In the English-only condition, teacher talk consisted of explanations and instructions in English. Language functions such as questioning, prompts for peer-report, and post-laboratory discussions were also in English. The instructors were directed to use Igbo only when absolutely necessary to communicate a safety instruction. In the Igbo-only condition, each of the above language functions was carried out in Igbo. When a term in Igbo was not readily available to represent a specialised concept in Chemistry, the teacher provided an explanation in English and/or the internationally recognised symbol or formula.

This was done to avoid use of a terminology that was technically incorrect. In the bilingual condition, teachers foregrounded English in eliciting responses to mathematical equations and nomenclature and assessments while Igbo was foregrounded in other situations. In both cases, teachers integrated both Igbo and English for pupils to express their conceptual understanding of the subject matter and directed learners to meanings in the two languages. National policies maintain English as the primary language of instruction. The Igbo-only condition was an alternative language of instructional condition to assess pedagogy and effects and was not intended to amend or replace the existing national policies (Federal Ministry of Information and National Orientation, 2025).

E. Equivalence and Language-specific Treatment Rules

- Participants were randomly assigned to
- An English-only group
- An Igbo-only group or
- A bilingual English-Igbo group.

Members of each group completed equivalent laboratory procedures using virtually available chemistry contexts.

1. Group A:

Members of this group conducted laboratory work in English for:

- Explanation
- Questioning
- Peer report
- Consolidation.

They prepared for the work virtually and enacted it physically, followed by a virtual consolidation. Group a members used English to work with culturally contextualized chemistry.

2. Group B:

Members used Igbo to explain and to question. In addition, they used symbols to represent meanings. Group b members prepared for the work virtually, enacted it physically, and consolidated it virtually. They used Igbo to interact with culturally contextualized chemistry. Group c: This group used translanguaging, that is, they used Igbo to elicit meanings and English to bridge the work and for assessment. This group also prepared for the work virtually, enacted it physically, and consolidated it virtually. This group also used culturally contextualized chemistry.

Table 3. Experimental equivalence and language-specific treatment rules

Condition	Language protocol	Laboratory sequence	Indigenous-knowledge content	n
English-only	English for explanation, questioning, peer reporting and consolidation	Identical virtual preparation + physical enactment + virtual consolidation	Identical culturally grounded chemistry contexts	120
Igbo-only	Igbo for explanation, questioning, peer reporting and consolidation; symbols retained	Identical virtual preparation + physical enactment + virtual consolidation	Identical culturally grounded chemistry contexts	120
Bilingual Igbo-English	Planned translanguaging: Igbo for elicitation/meaning-making; English for formal terminology and assessment bridging	Identical virtual preparation + physical enactment + virtual consolidation	Identical culturally grounded chemistry contexts	120

Note: Language condition is the intended systematic contrast; laboratory modality, content and instructional time are held equivalent.

A. Indigenous knowledge-integrated chemistry content

In the Chemistry programme, different cultural practices and beliefs were used as starting points to help learners understand different concepts in Chemistry. For example, to help

learners understand the concepts of chemical change and reaction, educators made use of practices associated with food and drink fermentation, and palm wine fermentation. Discussions on the nature of gas and acids and bases were derived from local practices of soap making. The correlation between oil and water was presented in relation to the local practice of oil palm processing. The practice of soap making was also used to explain the process of saponification. Community members' knowledge of corrosion of different metals was used to conceptualise the concepts of corrosion and redox reactions. Spiritual and cultural practices of the community were not treated as final and absolute truths, and educators encouraged learners to formulate hypothesis based on the chemical information derived from the practices and beliefs of the community.

B. Outcome measures

The two main outcome variables in the study were conceptual understanding and practical performance. Conceptual understanding was measured through the Chemistry Conceptual Understanding Test (CUT). The test is scored from 0 to 100 and is open-ended to evaluate learner's explanation and transfer ability. The test includes items that require learner to analyses and explains chemistry concepts at macroscopic, symbolic and sub microscopic levels. Practical performance was evaluated by the Chemistry Practical Skills Performance Assessment (CPSPA). Similar to the CUT, the CPSPA is scored from 0 to 100 and evaluate learner's ability to carry out laboratory activities, professional judgement and safety, and interprets laboratory results. Performance assessments in a laboratory setting allow examination of student's practical skills. Pre- and post-intervention assessments were completed to gauge student's performance without requiring student to rely on memory (i.e. post-test-score gain).

C. Instrument language and measurement equivalence

Given that language was the core of the intervention, care was taken to measure the outcome in the same language. It was assumed that the knowledge tested through English-language CUT may have been developed through Igbo. Likewise, an Igbo-only CUT may have benefitted the indigenous-language condition and resulted to overestimation of student's formal knowledge of chemistry. The authors therefore developed a bilingual CUT to balance conformity with measurement of student's knowledge and understanding of concepts of chemistry. Student were free to express their response in English or Igbo or any other form that is suitable and comfortable for them. While the test items may be expressed in two languages, interpretation of student's performance was made in Chemical terms and not in language used. Similar approach was taken for measuring student's practical skills.

D. Fidelity and implementation quality

Treatment fidelity was monitored to minimise contamination of the contrast. In the English-only condition, constant translation would quickly exhaust the limits of straw. In the bilingual condition, repetition of sentences verbally or in writing would be considered strategic translanguaging and would not have contaminated the contrast. Language use during the lessons was recorded by classroom observations and through self-checklists and audio samples completed by teachers. Fidelity was also monitored by comparing the teachers' adherence to the provided protocol and examples, participation in laboratory activities, and the time spent on each virtual activity. Additional variables included the completion of virtual

laboratories and engagement in other lessons and activities. Teachers received additional language guidance based on the conditions, so it was not unintentionally confounded.

E. Field data collection and dataset structure

Data were collected from all 360 SSII chemistry students. The data were collected from the 30 public secondary schools that were sampled. Each of the students provided data on their understanding and skills before and after the intervention. They also provided contextual data on state, locality, sex, school cluster, and the language of instruction. The data were analysed with regard to students who were in the same school. In cases where data were not comparable before the intervention, they were used as covariates in the posttest scores. The post test scores of the students in the three instructional language condition (English-only, Igbo-only, and bilingual Igbo-English) were the main foci for the analysis.

F. Statistical analysis

The analysis consists of four components. First, for each of the three groups defined by instructional condition, descriptive statistics are computed for pretest, posttest and gain scores. Second, to analyse baseline differences, one-way analyses are performed. Third, to analyse variance in the group's command of the language, function and state, locality, and sex are included, and the posttest is analysed. Language condition is the fixed factor. Hypothesised slopes are investigated by including pretest- by- condition interaction terms. Fourth, Levene-like procedures are used to analyse residual variance. Last, using the Holm procedure, planned pairwise comparisons of adjustment means are made. In studies dealing with language, having a command of language in everyday activities is the primary focus, and smaller command of language in other activities is assumed to be related. Thus, partial eta-squared is reported to assess the effect size of the language command in other domain activities. The statistical significance level is set at $\alpha = .05$.

G. Ethical considerations

The study includes research on human subjects, and therefore, the requirements of applicable educational institutions' research ethics committees have been observed. Prior to publishing, the study team will remove this document from the study records and replace it with the written report of the ethics committee that evaluated the study, the reference and approval number, the permissions of the research and educational authorities, and the processes for obtaining assent/consent of the participants. The study authors had no control over the language research condition, and it was described to participants as an educational research study to compare teaching different aspects of the school subjects in Igbo and English. The researchers guaranteed participants' confidentiality, and participants were free to withdraw from the study at any time.

IV. RESULTS

This paper reports data from 360 participants across all conditions. Prior to the interventions, mean conceptual and practical scores in all groups were in the low to mid-40s. After the interventions, mean scores in all groups increased, with the greatest improvement in the bilingual condition, followed by the Igbo condition and English condition.

Table 4. Descriptive statistics for the three-group field dataset

Group	n	Concept pre M (SD)	Concept post M (SD)	Concept gain M (SD)	Practical pre M (SD)	Practical post M (SD)	Practical gain M (SD)
English	120	43.54 (8.25)	62.42 (8.44)	18.88 (7.86)	40.95 (8.28)	62.08 (8.02)	21.13 (8.54)
Igbo	120	44.67 (8.70)	68.77 (8.25)	24.10 (7.93)	40.90 (7.90)	65.02 (8.43)	24.12 (7.32)
Bilingual	120	45.25 (8.58)	74.70 (8.05)	29.44 (7.75)	40.79 (7.80)	69.82 (9.20)	29.03 (8.52)

Note: Values are based on primary field observations collected from participating students.

A. Baseline equivalence and assumptions

Equivalence and assumptions were based on statistical results from the pre-test. Concerning the pre-test assumptions for the conceptual framework, the results of analysis of variance (ANOVA) indicated that there was no significant difference among the groups ($F(2, 357) = 1.25, p = 0.287$). The results further indicated that there was no significant difference among the groups for the pre-test assumptions for practical skills ($F(2, 357) = 0.01, p = 0.988$). Tests for interaction (pretest by language) to assess homogeneity of regression slopes for the two frameworks yielded non-significant results. Asymptotic Levene's tests showed that there was no significant difference for the two frameworks (Conceptual framework: $F(2, 357) = 0.53, p = 0.592$, Practical skills: $F(2, 357) = 0.88, p = 0.415$). Based on the diagnostic checks, it was justified to rely on the post-test to assess frameworks for the three conditions.

B. Conceptual understanding

Results of the conceptual post-test showed that participants assigned to language-related conditions scored higher than those who were not assigned to any conditions, $F(2,350)=83.40, p<.001$, partial eta-squared = .323. The School-cluster-sensitivity test came to the same conclusion, Wald chi-square (2) =174.19, $p<.001$. The means adjusted for language conditions were as follows: English-only instruction, $M = 62.93$ (95% CI = 61.47, 64.39); Igbo-only instruction, $M = 68.67$ (95% CI = 67.06, 70.28); and bilingual instruction, $M = 74.29$ (95% CI = 73.37, 75.20). Language conditions accounted for a large amount of post-test variance. The difference between the means for the highest (bilingual instruction) and the means for the lowest (English-only instruction) language conditions were 11.36 points on the 100-point scale of conceptual understanding.

Table 5. ANCOVA language effects and adjusted means

Outcome	F (df)	p	Partial eta ²	English adj. M [95% CI]	Igbo adj. M [95% CI]	Bilingual adj. M [95% CI]
Conceptual understanding	83.40 (2, 350)	< .001	.323	62.93 [61.47, 64.39]	68.67 [67.06, 70.28]	74.29 [73.37, 75.20]

Practical skills	35.29 (2, 350)	< .001	.168	62.04 [59.82, 64.26]	65.01 [63.67, 66.35]	69.87 [67.74, 71.99]
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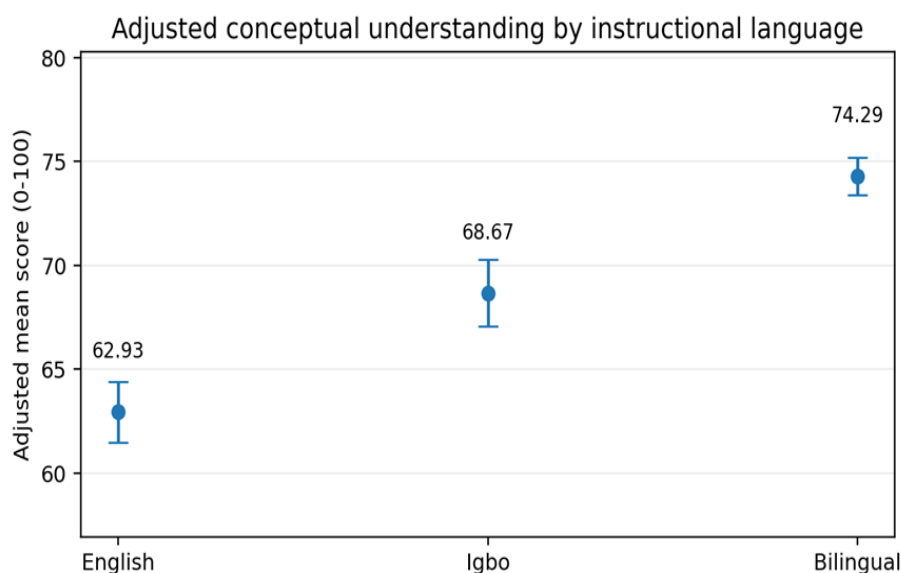


Figure 1. Adjusted conceptual understanding means with 95% confidence intervals

Holm-adjusted pairwise comparisons showed all three means of conceptual understanding differ from one another. Igbo was higher than English by 5.74 (95% CI 3.56, 7.92), $p < .001$. Bilingual instruction was higher than English by 11.36 (95% CI 9.63, 13.08), $p < .001$, and higher than Igbo by 5.62 (95% CI 3.76, 7.47), $p < .001$. Overall, results obtained from the field showed that bilingual > Igbo > English with respect to concepts understood and was not necessarily due to an extreme condition.

C. Practical skills

The Holm-adjusted language effect is also significant for practical skills, $F(2, 350) = 35.29$, $p < .001$, partial eta-squared = .168. The school-cluster-robust Wald test was also significant, Wald chi-square (2) = 25.99, $p < .001$. The adjusted means were 62.04 (95% CI 59.82, 64.26) for English, 65.01 (95% CI 63.67, 66.35) for Igbo and 69.87 (95% CI 67.74, 71.99) for bilingual instruction. The difference between means for bilingual and English was 7.83, which was also observed for the conceptual case. As expected, for practical skills, the difference between the means was smaller than what was observed for conceptual case. This was also in line with the expectation for the means for practical skills case.

After applying the Holm adjustment, all comparisons of practical skills remained significant. However, the English-Igbo comparison came much closer to the .05 significance level and was only significant due to the liberal application of the adjustment. Igbo was higher than English by 2.97 points (95% CI 0.37, 5.57) and the adjusted p-value was 0.025. Bilingual instruction was higher than English by 7.83 points (95% CI 4.75, 10.90) and the adjusted p-value was less than 0.001 and higher than Igbo by 4.86 points (95% CI 2.34, 7.37) and

the adjusted p-value was less than 0.001. Hence, results based on practical skills paralleled the conceptual results, however the differences were smaller, particularly the English-Igbo difference. Based on these results, both null hypotheses are rejected.

Table 6. Holm-adjusted pairwise language contrasts

Outcome	Comparison	Adjusted difference	95% CI	Holm p
Conceptual understanding	Igbo - English	5.74	[3.56, 7.92]	< .001
Conceptual understanding	Bilingual - English	11.36	[9.63, 13.08]	< .001
Conceptual understanding	Bilingual - Igbo	5.62	[3.76, 7.47]	< .001
Practical skills	Igbo - English	2.97	[0.37, 5.57]	0.025
Practical skills	Bilingual - English	7.83	[4.75, 10.90]	< .001
Practical skills	Bilingual - Igbo	4.86	[2.34, 7.37]	< .001

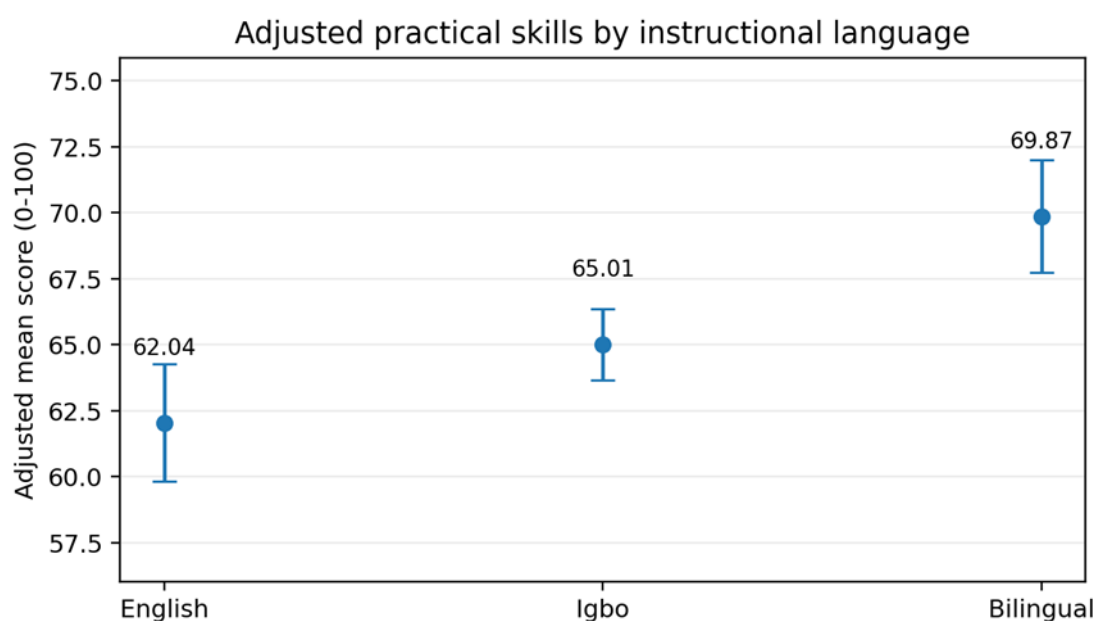


Figure 2. Adjusted practical skills means with 95% confidence intervals

V. DISCUSSION

The results largely show a clear hierarchical arrangement of the three instructional conditions. Among the conditions, the use of bilingual Igbo-English produced the highest adjusted means, conceptual and practical, of all the instructional conditions. Use of Igbo-only was next, with the use of English-only at the bottom, producing the lowest adjusted means. Variables for sex, locality, state, and test score were included in the adjustment models for the post-tests. Because of this, it may be difficult to explain why the results were as they were. The adjusted estimates, however, remain significant with school-level clustering. Considering the nature of the research design, the results provide evidence of an association between the use of language for instruction, and conceptual and practical

outcomes. It should be kept in mind that the results of this research do not demonstrate the effects of using specific languages for instruction, in a broad sense.

The results of the present study support the notion of recent translanguaging studies. Kiramba and Charamba (2023) and Charamba (2023) indicate that learners are able to use the different languages available to them to construct epistemological access and scientific explanations. In turn, He and Zhou (2024) suggest that the use of translanguaging in secondary English-medium science classes is valuable for students to gain their conceptual understanding of science. In this study, bilingual conceptual mean in the adjusted form, was approximately 11 points above English and 5.7 points above Igbo. Linguistic complementarity appears to be an adequate explanatory framework. It is suggested that, in addition to English, Igbo plays a key role in composing scientific meanings. From the perspective of teaching chemistry, it can be argued that Igbo provides means for learners to linguistically construct and articulate relevant (experiential) meanings in the domain of chemistry and science, while English offers the means for learners to formulate and express more abstract scientific meanings, and for assessment.

The difference in perception of Igbo vis-à-vis English also corroborates some existing data. Chukelu and Nkok (2024) asserted that in basic science, instruction through the medium of Igbo in public schools of Imo State had positive effects on student performance. In a similar vein, Bosah et al. (2025) concluded that the use of basic science mother-tongue instruction in Anambra State had a positive effect on basic science performance. Regarding science education in senior secondary schools, Oso (2024) supports integrating vernacular and English languages in the delivery of science teaching. Regarding teaching chemistry, the researcher posits that instructing chemistry through the medium of Igbo language, for example, may facilitate students' explanation of the role of causal variables including temperature, exposure and time, for a given chemical reaction that they have prior knowledge. This is particularly so if students are unable to communicate their causal relationship with chemistry variables through the English language. In this regard, information provided by students in the medium of Igbo can be critically evaluated.

Though the strength of bilingual education versus Igbo-only education should be assessed considering the specific environment where the education is delivered, it is important to consider the limitations of the Nigerian educational system. English is the official and main medium of expression for textbooks, standardised examinations, and scientific nomenclature. In November 2025, the Federal Government re-affirmed that English would remain the official medium of instruction at all levels of education. Advocates of English-only instruction have cited standardization and consistency in the education system of a multilingual country, availability of instructional materials, adequate preparation of teachers and other personnel, and alignment with the examination systems of WAEC and NECO, as well as JAMB and university-level education. Obiakor (2024) argues that the use of indigenous languages in instruction does not guarantee improvement in the absence of proper planning and adequate educational policies. English, in this case, is not scientific by nature, but there is a need to help students understand formal science and, more importantly, the schooling process, which is evaluated and formally rewarded through school science.

There is ample reason to believe that integrating the science of chemistry into Nigerian students' vernacular may better facilitate schooling than the monolingual English approach. The integration of Igbo, or the student's language of everyday life, into the policy may help scientists reach conclusions that are otherwise beyond students. From the SSII chemistry

approach, English may be the medium of communication in school for science and chemistry, while Igbo may be used to help students communicate ideas and chemical conclusions that they previously could not.

The adjustments in conceptual skills differ from practical skills. The partial eta-squared difference between conceptual skills (.323) and practical skills (.168) demonstrates that while participants rely on the equipment and processes before them to attain the skills, the reasons and means for attaining the outcome may differ. Understanding practical skills involves working with equipment, manoeuvring the system, and interacting with the constraints of the medium. Using language to explain the means and the reasoning for the outcome may help clarify the process, but performing the process itself helps strengthen the skills. While there are advantages to using virtual labs, they should not be relied on to replace actual practical laboratory work. As demonstrated in Konyefa (2026), off-line virtual activities can assist in attaining practical skills, as shown with titrations. Furthermore, as demonstrated in Anari et al. (2026), various other practical skills and their related retention can be improved with the judicious use of technology. The predominant use of technology to accomplish practical skills is reserved for preliminary and supporting activities. Direct practical skills activities are retained.

A consideration of the relatively small Igbo-English difference on the practical sheet gives more information and illuminates conceptual differences. The Igbo-English difference on the practical sheet yielded an adjusted score of 2.97 at $p = .025$, thus indicating statistically significant results. Conceptual differences were stronger, and therefore not as susceptible to sampling and implementation differences. On the other hand, particularly in chemistry, where factors affecting successful conceptualization are not as clear and require a series of practice and demonstration, performance on practical activities may be less demanding. Since conceptual and practical differences affect a combined chemistry score, reporting may need to be on a practical or a procedural score to bring out differences that may be conceptual.

The impact of languages varies depending on the other factors affecting integration. Igbo/bilingual teaching and learning is likely to be of great benefit to the teaching and learning of chemistry and other sciences if the experiences and observations gained by the students as members of the local community are the focal points of interactions. The interpretation of the impact of the use of Igbo and English also varies with other contexts. For example, Eze et al. (2025), Umahaba (2026), and Jack and Famiwa (2026) provide information on the integration of ethnoscience with chemistry in diverse contexts. In the study, the learners investigated a series of relationships, exemplified and mediated by language, among various states of matter and mechanisms that are not visible. They conducted a series of laboratory experiments to test their hypotheses.

The quality of implementation remains key to understanding these findings and determining how widely they can be generalised. Most educators in the studies cited in this review are schooled in Igbo up to the level of spoken language and require more training to understand how to describe causal relationship in science without reinforcing scientifically incorrect concepts. This requires a depth of scientific understanding of concepts together with cultural sensitivity to authentically teach in community context while valuing community knowledge. Mlotshwa and Tsakeni (2024) demonstrated how integration of IK in practical science teaching enhances the acceptance and teaching of the concepts of science. Simasiku and Ngcoza (2024) also share challenges encountered when trying to teach acids and bases using practical activities. Hence, preparation of teachers to handle language, culturally

relevant queries and terminology, virtual laboratory and other practical activities must be of high priority. Fidelity in fidelity monitoring is of paramount importance because teachers trained to use IkBr are likely to use 'bilingual drifting' in English-only classes or 'uncontrolled' bilingual teaching which may impact negatively on teacher-pupil interaction and treatment fidelity.

The research adds to the body of knowledge on creative integration of IK in education to enhance science teaching in the community, and also identifies challenges facing teachers when teaching the acid base concept using practical activities. To test scientific concepts, teaching aids and learning materials must be developed to reduce risks of language variation. These items must also be validated to minimise risks of differential item functioning. Given the emphasis on practical teaching of chemistry and written language, this research may have reduced validity and reliability, respectively. Measurement invariance must be assessed and reported in future studies.

Several limitations exist regarding the interpretation of findings. First, due to the nature of the design, causal conclusions are limited. However, several analytical strategies (i.e. baseline equivalence, covariate adjustment, cluster-robust analyses) reduced the threat to internal validity. Second, the ways in which intervention was implemented may have differed across teachers due to a variety of factors, including the teacher's command of English and Igbo, as well as the availability and quality of school resources. Third, the adoption of indigenous knowledge varies by community. Fourth, findings from this study may not be generalizable to other communities outside Abia, Anambra, Ebonyi, Enugu and Imo States. Finally, because the intervention lasted for six weeks, the effects documented may have already dissipated. Further, retention, generalization and transfer to other domains and contexts were not evaluated. It is unclear if the advantages documented by the study would be evident beyond the local school environment. It is also unclear if improvements would be evident in similar communities outside of the 20 public coeducational schools in South East Nigeria studied. Because settings, schools and communities may vary, care is warranted when generalising findings outside the study.

In spite of the constraints noted, the study makes a significant contribution to research by integrating four different research traditions, which are studied separately. These include the language of instruction, translanguaging, indigenous knowledge and blended laboratory pedagogy. Other scholars' work have documented each of these traditions, but have not explored their intersection in south eastern Nigeria's senior secondary chemistry. The present study is the first to provide field evidence for the role of language in mediating blended laboratories. The evidence obtained shows that different languages can lead to differences in learners' understanding of chemical concepts and their performance in laboratory work. Hence, the main policy suggestion is not to advocate for the replacement of English with Igbo, but to adopt a structured bilingual (or multilingual) approach to the integration of Igbo into the teaching of chemistry.

VI. CONCLUSION

Field data revealed no significant differences in baseline for either outcome. Posttest data differed significantly. For outcome 1, bilingual instruction ranked highest, followed by Igbo-only instruction and English-only instruction; pairwise comparisons were significant, post Holm correction. For outcome 2, English-only instruction ranked highest followed by bilingual instruction and Igbo-only instruction; pairwise comparisons were significant, post

Holm correction. The conceptual effect of language was greater than the practical effect, indicating that language, in this case, Igbo, was particularly useful when the learners needed to link culturally-relevant experiences and representations with formal explanations. The results of this study demonstrate the use of Igbo and English to serve particular functions in the context of senior secondary chemistry, and that the two languages can be harmoniously integrated in bilingual instruction. The integration of this model does not have to be limited to chemistry. Other subjects, including English language teaching, can benefit from this model. The use of Igbo and English in this model can be assessed for senior secondary in other geo-linguistic regions of Nigeria.

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