Zamfara International Journal of Education
The Official Journal of Faculty of Education
Federal University Gusau, Zamfara State, Nigeria
Maiden Edition (Volume 1, Number 1)
June, 2021
www.zijedufugusau.com

Model-Based Inquiry as a Viable Strategy for Chemistry Instruction in Colleges of Education in Nigeria: An Overview

Sa'idu DANLADI Ph. D.
Email: saidanladi@slu.edu.ng
Science Education Department, Faculty of Education, Sule Lamido University, Kafin Hausa

Abstract

Chemistry education at the National Certificate in Education (NCE) level is designed to produce competent chemistry teachers with the capacity to further encourage the spirit of inquiry and creativity in the learners and to apply the skills and knowledge to solve day-to-day problems. These objectives are yet to be appreciably achieved because of the glaring mismatch between the quality of pre-service Chemistry teachers and their service delivery. The ability of Pre-service Chemistry teachers in particular to select and utilize the appropriate instructional techniques in their delivery, is a function of the training they received from Colleges of Education (COEs). However, COEs often fail to equip pre-service teachers for their obligations in workplaces due to reliance on ineffective teaching methods. Thus, pre-service teachers are rendered passive and observers rather than being active participants in the classroom. These practices impede their interest and the acquisition of requisite knowledge and professional skills. Educators recommended the use of activity-based strategies such as the inquiry. Despite the merits of inquiry approach, it has not been satisfactorily utilized to produce the desired result as students still do laboratory verifications by closely following directions and memorizing what textbooks and/or lecturers indicated as truth about the natural world. Hence the proposition for the use of reformed innovative inquiry approaches such as Model Based Inquiry (MBI). The activities in MBI focus learners not only on investigative material activities as in the Conventional Inquiry (CI) but also on deep subject matter understanding and the provision to develop a platform of understanding (a model) to inform their previous knowledge, questions and hypotheses. The paper gives a rationale for this optimism and a sample lesson plan to this effect. It has been recommended that teacher educators adopting MBI must not make inquiry/modeling processes too abstract to enable prospective teachers apply the experience at places of their primary assignment.

Keywords: Model –Based inquiry, Conventional Inquiry, Chemistry Education, Pre-service Teachers

Introduction

The idea of teaching science by inquiry method which allows students to explore, and experiment with their own concepts about science is often referred to as inquiry-based learning. In inquiry-based instruction, the goal of the instructor is to assist with information processing, to facilitate group discussion, to guide student action, and to increase student thinking. Inquiry approach is an instructional practice where students are at the center of the learning experience and take ownership of their own learning by posing, investigating, and answering questions (Caswell & LaBrie, 2017). It is also considered a form of self-directed learning where students take responsibility for their learning (Spronken-Smith & Walker, 2010). It is therefore pertinent to note that developing in the learners the requisite knowledge, interest and skills that are relevant in this millennium requires a learning environment that mirrors the inquiry setting.

Although the use of conventional inquiry approach has been recommended in the teaching of science in general, some researchers and science educationist have indicated some level of apprehension (Danladi, 2019). Corroborating further, Nwosu (2015) indicate the continuous abuse/misuse of inquiry as verification activities, where students closely follow directions and memorizing what science teachers and text books have indicated as truth about the natural world. In such process, Witt & Ulmer (2010) states that students tend to regurgitate with only minor variations, the steps of inquiry: observe, develop a question, develop a hypothesis, conduct an experiment, analyze data, state conclusions and generate new questions. The requirements of the 21st century include the ability for students to critically and creatively solve problems and respond to changes in economic and social conditions defined by the level of their knowledge and skills for success in their work places and personal lives. Hence, the proposal for a shift to a more innovative form of inquiry, grounded in reasoning with and about models, such as the Model-Based Inquiry (MBI). However, the ability of College Pre-service Chemistry teachers to appreciate, use or adopt the MBI in particular and other inquiry based learning approaches in general, squarely depend on their lectures' capability and willingness to select and maximally utilize these methodologies.

Rationale for College Chemistry instruction using Model-Based Inquiry

The potentials of Chemistry education in providing the desired national sustainability is mirrored in the intents of its inclusion in the nation's curricular packages at different educational levels. At the basic education and secondary school levels, the learning experience is aimed at the acquisition of appropriate level of literacy, numeracy, manipulation and life skills such as the critical thinking and creativity for useful living within the society (FRN, 2014). At the National Certificate in Education (NCE) level, chemistry education is designed to produce competent chemistry teachers with the capacity to further encourage the spirit of inquiry and creativity in the learners and to apply the skills and knowledge to solve day-to-day problems (National Commission for Colleges of Education, 2012). However, these objectives are yet to be appreciably achieved in our schools and colleges because of the mismatch between the quality of pre-service Chemistry teachers and their service delivery at basic and secondary school levels (Junaid, 2014; Shuaibu, 2014). The dwindling quality of college pre-service chemistry teachers according to Rufa'i (2013) reflects to some extent the nature of the tunnel-vision teacher preparation packages in Colleges of Education. This results in low level of performance of the products of COEs in places of their primary assignment typified by their poverty of knowledge of the subject matter and teaching skills (Agoro, 2013).

Science educators have identified some factors militating against the production of proficient chemistry teachers with the requisite professional competencies, to include teachers' and lecturers a like in the use of ineffective strategies in their instructional deliveries. However, the ability of Chemistry teachers in particular to select and utilize the appropriate instructional techniques in their delivery, is a function of the pre-service training they received from the teacher producing institutions and departments. The quality of teachers is dependent on their preparation for professional role as distinct practitioners (Aina & Akintunde, 2013). In Nigeria however, low level of performance of pre-service teachers, especially their poverty of knowledge and skills has been a recurrent problem in science education (Agoro, 2013; Ijaiya, Alabi & Fasasi, 2011). The identified weakness raises the concern about pre-service Chemistry teachers' ability in particular to prepare students for the 21st century knowledge society. Quality of teacher education programs and the ability/willingness of the COEs and universities to provide for innovative programs that will produce better prepared teachers are being questioned (Agoro, 2013). There is an overall lack of political and public confidence in teacher training systems and a profound mismatch between the radically new key competencies demanded from students in the knowledge society and the teaching skills that pre-service teachers are equipped with, in teacher training institutions (Agoro, 2013). The major reason for this problem advanced by some educators is that pre-service teachers' preparation programs in College and by extension the universities, were based predominantly on traditional practices in their instructional deliveries (Agoro, 2013; Ijaiya et al, 2011). Since there is no automatic connection between education and the needed sustainable development except through a good pre-service teacher preparation programs, the need for teacher educators to adopt innovative strategies becomes essentially paramount. This underscores the need, more than ever before, for Chemistry Teacher educators especially at COE level to adopt innovative teaching strategies such as the MBI.

Nevertheless, the need for exposing the prospective science teachers at higher education levels to quality knowledge and skills, both practical and cognitive, remains a necessity (Danladi, 2016). Science educators maintain that the task cannot be accomplished without a radical change from the use of teacher centered and traditional practices in teacher preparation programs to the use of Inquiry among student centered approaches. Inquiry-based learning ranges from structured through guided activity to open inquiry (Inoue and Buczynski, 2011). However, research findings such as Choi, Klein & Hershberg (2014), Nwosu (2015) and Danladi (2016) indicate the continuous abuse of the Conventional Inquiry (CI) as verification activities where students closely follow directions dictated by lecturers' laboratory manuals and memorizing what science lecturers and text books have indicated as truth about the natural world. This lead to the proposition by science educators for a more innovative inquiry based instructional technique such as the Model-Based Inquiry (MBI), to re-focus the processes of conventional inquiry (CI) with requirements of the millennium. Further justification for the use MBI over the CI in college Chemistry instruction is reflected in a study conducted by Danladi (2016). The study revealed the efficacy of the MBI on the pre-service teachers' creative and critical thinking skills acquisition and interest in Chemistry with the male and female students having almost equal learning opportunities.

Conventional Inquiry

Inquiry, in different guises and with different terms, has been cited as one of and often the principal goal of science education for decades. In science education, the term inquiry refers "to a process of seeking knowledge, raising questions, searching answers, evaluating information and asking new questions" (Virginia & Whitney, 2011). This leads to a practical connection between students' prior knowledge and scientific descriptions of natural world thereby opening up their windows of opportunities to explore natural world themselves (Panasam & Nuangchalem, 2010). Inquiry-based learning ranges from a rather structured (the teacher provides students with a question and the process students use to find the answer) through guided activity (the teacher poses a question and provides the students only with materials to be used in their investigations), to open inquiry in which teachers furnish students with materials to investigate but students must come up with questions and methods for investigation (Inoue and Buczynski, 2011). The learning outcomes of inquiry include critical thinking, the ability for independent inquiry, responsibility for own learning and intellectual growth and maturity.

In the science classroom, labs are an essential component to learning. Minner, Levy and Century reported by Idleman (2016) believe that utilization of, "hands-on experiences with scientific or natural phenomena were found to be associated with increased conceptual learning. The lab experience begins with an observation or the posing of a question. An experiment is then designed to solve the problem. Through inquiry based learning, students are able to verify or refute preconceived beliefs through first hand, hands on experience in the lab. Sesen and Tarhan (2010) found statistically that, "applications cause a significantly better acquisition of scientific conceptions, and ensure positive attitudes toward chemistry lesson in comparison with traditional instruction. A number of additional studies have attested to the efficacy of conventional inquiry in science instructions. Such studies range from students' achievement (Idleman, 2016, Adeyemi & Adeyemi, 2014, Araoye, 2013) to skills acquisition (Karpova, Marcketti & Berker, 2011, Danladi, 2016 and students teachers' challenges and perceptions (Gholam, 2019). However, beside the richer educational experience it provides through active involvement of students in science classrooms, students may continue to do verification activities closely following directions and memorizing what science teachers have indicated as truth about the natural world. Probably introducing modeling (physical and mental) into the conventional forms of inquiry may probably upgrade the inquiry processes to align with the skill requirements of 21st century. This may perhaps bring about improvement in the active involvement of science students in the instructional processes.

Model based Inquiry as Shift from CI in Teaching Chemistry

Model-Based Inquiry (MBI) is an instructional technique in which science students utilize models as representations of physical properties such as characteristics, entities, and conceptual relationships blended in inquiry process. (Passmore, Stewart & Cartier, 2010) state that in MBI, students try to grasp the properties of an existing models (learning from models), learn from creating models (learning by modeling) and a way of learning in which these two forms are combined. In MBI, unlike the conventional inquiry, direct experiment is not the only source of data, it provides students with the opportunity to develop initial platform (a model), connects investigative science (not necessarily laboratory but even the library) and content and entails not only about patterns in observable relationships but about how these relationships act as evidence for why a phenomenon happen in a particular way (Windschitl, Thompson & Braaten, 2008). In sum, conventional inquiry focused on testing hypothesis while MBI is grounded in content, goes beyond how something happens (testing hypothesis) to why something happens i.e. testing idea (Louca, Zacharia, & Constantinou, 2011). Following are two vivid examples that substantiate the striking differences of testing hypothesis in conventional inquiry to testing of idea in MBI. Example 1: in an activity involving the determination of dissolution of different sizes of sugar crystals, the smaller sugar crystals will dissolve faster than the larger sugar crystals (CI) but in MBI, the underlying explanations based on the analyses of how molecular motion helps break the chemical bonds between molecules of sugar will be addressed. Example 2: was provided by Windschitl et al. as reported by Danladi (2016) in their attempt to investigate on scaffolding involving two pre- service teachers Kyle and Jeanne. In a study where participants were not given scaffolding, one of pre-service teachers, Kyle, conducted an experiment in which he compared the water retention capabilities of different brands of diapers. His hypothesis was simply a guess about which brand would hold the most water based on perceived thicknesses of the samples. His conclusion was about which sample held more water, but Kyle made no suggestions about how or why water might be retained differently by one diaper versus another. This investigation was entirely devoid of conceptual content that could explain the outcomes. Jeanne in a later study investigated how fabrics absorb liquids. Members of her pre-service cohort, however, were required to "create an initial representation of the phenomenon" they were interested in, to "test a piece of that model" and to culminate their investigations by "connecting empirical findings with an underlying cause." These requirements prompted her to do background reading in both material sciences and the chemistry of liquid–fiber interactions. She found supporting evidence for a hypothesis that various fabrics, based on their molecular structure, would absorb different amounts of neutral, acidic, and basic solutions. She then used her findings to support her theory about unseen molecular-level interactions that explained the empirical outcomes (referred to as theory-directed argument). These two cases illustrate what is meant by testing a hypothesis (Kyle) versus testing an idea (Jeanne).

The MBI enables students to develop and justify explanations and give them the opportunity to develop meta-knowledge in scientific practices and understanding of both content and process of science (Passmore, Stewart & Cartier, 2010). These aspects of the MBI having the potential of wider applicability should expectedly be imbibed by pre-service chemistry teachers during training at the COEs and Universities for success in their work places and personal lives.

Advantages of MBI

Students exposed to MBI instructional strategy will have the following learning opportunities;

1. Collaborative learning experiences
2. Connect investigative science and curricular contents
3. Extend their knowledge from HOW something happens to WHY it happens
4. Cover the contents in the overloaded curriculum
5. It has zero tolerance to passive learning.

Sample Lesson plan on Chemistry Instruction using MBI

There are possibly many approaches to implementing the MBI in our classrooms as are likelihoods for other forms of inquiry techniques. The suggestion of Windschitl et. al. as cited in Danladi (2016) will probably be one of the seemly apt versions. This proposal begins with the teacher setting the general parameters of what will be studied. This is followed by four kinds of intellectual activity/conversation engaged in by students. These activities/conversations are; organizing what we know and what we need know, generating hypotheses, seeking evidences and constructing argument. These steps are procedural not linear as in the CI.

Level	NCE 11
Duration	4 Hours
Instructional Materials	University Organic chemistry: The fundamentals, or any A level organic chemistry texts, cardboard papers, Masking tape, permanent markers (different colors), clay or any suitable material that could be used for modeling
Instructional Objective	At the end of the lesson, pre-service teachers should able to describe and model the geometry of saturated hydrocarbons
Previous Knowledge	They were taught hybridization and the chemistry of hydrocarbons
Presentation	The lesson will be presented based on the following steps of MBI
Step One: Test of previous Knowledge	The lecturer kick starts the inquiry process by asking questions (whole class) related to their experience centered on the different classes of hydrocarbons to assess their entry knowledge. The questions are; a. What is hybridization? b. Identify the relationship between hybridization and the atomic orientations in an organic compound Students are expected to raise areas of misconceptions and ask questions that may open-up their related knowledge. Based on their previous knowledge and ensuring that all misconceptions are clarified, the following MBI activities will be carried out.
Step Two: What we know and what we want to know.	The lecturer after ascertaining the level of students' previous knowledge should give an outline of the tasks in form of questions to be answered by the students in groups of about 10 guided by the following questions/activities or any appropriate alternative(s); ● Identify different types of bonding and figure out the crucial determinant of organic compound characteristics, ● What is hybridization? ● Identify the types of hybrid orbitals
Step Three: Generating hypothesis.	The lecturer articulates students' experience on the above questions and then provides guidance for students to propose sketch model (guess) of different molecular geometries of Methane and Ethane to form conceptual diagram using the cardboard papers and permanent markers. In groups, students should come up with representational models of the 2 saturated hydrocarbons taken one after another.
Step Four: Seeking evidence.	The lecturer scaffolds the students to identify sources of data to prove (or otherwise) the orientation of atoms in their respective group models. Students study and brainstorm the following questions/ activities to seek evidences to prove (or otherwise) their models,

	● what are the broad categorization of organic compounds? ● Identify sp^3, sp^2 and sp hybridization as basis for; i) classifying organic compounds, ii) molecular geometry in organic compounds, iii) determinants of bond angles ● How is σ bond formed? ● what is the place of molecular geometric orientations and the physical and chemical characteristics of the saturated Hydrocarbons?
Step Five: Constructing arguments.	The lecturer intervenes to clear misconceptions, guide transition from small groups to whole class discussion, facilitate the flow of argument and utilize students' experiences to create a whole class tentative representational model of the geometries of the hydrocarbons by group presentations. ● In groups, students should use the representational sketch (in the cardboard) to come up with a physical models of the geometries of the identified saturated hydrocarbons Students in groups will present their constructed models. Authentication of models follows. This will be guided by the following; ● identify what their respective models fail to predict/consider if any, ● should our model change in the light of any evidence from other group(s)? ● What makes our model different from other groups and why?
Evaluation	The lecturer evaluates the lesson by introducing propane (having three tetrahedrons) to find students' level of flexibility. They are expected to briefly describe the geometry of propane in such a way that it triples the geometry of methane and 1½ of ethane but with different orientations. Danladi (2016)

Conclusion

In MBI, teachers and lecturers alike are expected to direct their planning efforts primarily to the intellectual work students will do, rather than focusing on material manipulations. The intellectual discourse of the classroom, in turn, is shaped by the epistemic context of how knowledge evolves and utilized within the scientific community. As with other forms of inquiry, MBI can be more or less guided depending on the circumstances. For learners below the tertiary level of educational system, they would not be expected to incorporate highly abstract theoretical ideas into models or explanations. The use of MBI is therefore an attempt to re-orientate the common science inquiry practices in order to bridge the world of science and science education systems in an intellectually honest way. These aspects of the MBI having the potential of wider applicability should be imbibed by learners at colleges and universities for success in their work places and personal lives.

Recommendations

For effective implementation of the MBI during training and beyond, it is recommended that:

1. Lecturers and Teacher educators should resort to co-teaching where feasible, to enable them handle the activities of the unavoidable large groups of students as MBI is procedural as against the Conventional Inquiry
2. For Prospective teachers, the inquiry process/modeling in MBI **must not** be too abstract. This is to enable them apply the experience at places of their primary assignment.
3. Lecturers and Teacher educators must give students ample time to ask questions and necessary guidance. This is because scaffolding is absolutely necessary in MBI. There are no restrictions in terms of laboratory periods, group activities as in Conventional inquiry. As such students must utilize their time, including weekends besides the lesson duration for in depth readings/library research.

References

Adeyemi, A. M. and Adeyemi, S. B. (2014). Personal factors as predictors of students. Academic achievement in Colleges of Education in south western Nigeria. *Educational Research Reviews*, 9(4), 97-109. http:www.academicjournal.org/ERR

Agoro, A. A. (2013). Effects of reflective-reciprocal teaching strategies on pre-service teachers' achievement in integrated science and science process skills in Nigeria Colleges of Education. *World Conference in Science and Technical Education*, 29th September-3rd October, Sarawak, Borneo, Malysia.

Aina, J. K. and Akintunde, Z.T. (2013). Analysis of gender performance in physics colleges of education, Nigeria. *Journal of Education and Practice*, *4*(6), 57 – 71.

Araoye, M. I. (2013). Redressing students' motivation and academic achievement in Biolog education at F. C. E. (special) Oyo. *International Conference: New Perspectives in Science Education*, 2nd Edition, 1-6.

Caswell, C. J., & LaBrie, D. J. (2017). Inquiry-based Learning from the Learner's Point of View: A Teacher Candidate's Success Story. *Journal of Humanistic Mathematics*, *7*(2), 161- 186.

Choi, A.. Klein, V. and Hersberg, S. (2014). Success, difficulty and instructional strategy to enact an argument-based inquiry approach experiences of elementary teachers. I*nternational Journal of Science and Mathematics Education*. From htt:/www. Springer.com on 16th March, 2015.

Danladi, S. (2016). Effect of Model Based Inquiry Instructional Technique on Achievement, Skills Acquisition and Interest of Pre-service Chemistry Teachers Unpublished PhD Thesis, University of Nigeria, Nsukka.

Federal Republic of Nigeria. (2014). *National Policy on Education*. Abuja NERDC Press.

Gholam, A. (2019). Inquiry-Based Learning: Student Teachers' Challenges and Perceptions. *Journal of Inquiry and Action in Education*, 10(2), 113-133.

Idleman, B. D. (2016). Effectiveness of inquiry based instruction on students' achievement and attitude in high school Chemistry. [Masters dissertation, Montana State University].https://scholarworks.montana.edu/xmlui/bitstream/handle/1/10060/IdlemanB0816.pdf?sequence=6

Ijaiya, N. Y. S., Alaabi, A. T. and Fasasi. Y. A. (2011). Teacher education in Africa and critical thinking skills: Needs and strategies. *Research Journal of Business Management*, 5(1), 26-34. http//doi.org/ 10.3923/rjbm.2011.26.34.

Inoue, N. & Buczynski, S. (2011). You Asked Open-Ended Questions, Now What? Understanding the Nature of Stumbling Blocks in Teaching Inquiry Lessons. *The Mathematics Educator*, 20, (2), 10–23.

Junaid, M. I. (2013). Introduction to the Curriculum Implementation Framework for NCE. National Commission for Colleges of Education, Federal Republic of Nigeria.

Karpova1, E., Marcketti, S. B. & Barker, J. (2011). Efficacy of teaching creativity: Assessment of student creative thinking before and after exercises. *Clothing & Textiles Research Journal*, 29(1), 52-66. http// doi.org/ 10.1177/0887302X11400065

Louca, T. L., Zacharia, P. C. & Constantinou, Z. C. (2011). In quest of productive Model-Based learning discourse in elementary school science. *Journal of Research in Science Teaching*, 48(8), 919-951.

National Commission for Colleges of Education [NCCE], (2012). Nigeria Certificate in Education Minimum Standards for Sciences. Abuja, Federal Republic of Nigeria.

Nwosu, A. A. (2015). Science education for life in a dynamic world. An Inaugural Lecture of the University of Nigeria, Nsukka. Thursday, October 29th.

Panasan, M. & Nuangchelerm, P. (2010). Learning outcomes of project-based and inquiry-based learning activities. *Journal of Social Science*, 6(2), 252-255.

Passmore, C., Stewart, J. & Cartier, J. (2010). Model-Based inquiry and school science: Creating connections. *School Science and Mathematics*, 109(7), 394-402.

Rufa'I, R. A. (2013). Forewaord to the Curriculum Implementation Framework for NCE. National Commission for Colleges of Education, Federal Republic of Nigeria.

Sesen, B. A. and Tarhan, L. (2010). Promoting active learning in high school chemistry: Learning achievement and attitude. *Procedia-Social and Behavioral Sciences*, 2(2), 2625-2630. https//doi.org/10.1016/j.sbpro.2010.03.384.

Shuaibu, M. J. (2014). The structure, contents and expected delivery methods of the new NCCE Curriculum. A paper presented at the orientation of the new curriculum and college Re-structuring, Jigawa State College of Education, Gumel, 6 to 14th February, 2014.

Spronken-Smith, R., &Walker, R. (2010). Can inquiry-based learning strengthen the links between teaching and disciplinary research? Studies in Higher Education, 35(6), 723–740.

Virginia, L. W. & Whiteny, N. H. (2011). *Collaborating for Inquiry-Based learning: School librarian and teachers.* Pearson Education Inc.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-Based Inquiry as a new paradigm of preference for school science investigations. *Science Education*, 1-27, http//doi.org/ 10.1002/sce.20259.

Witt, C. and Ulmer, J. (2010). The impact of inquiry-based learning on the academic achievement of middle school students. 2010 Western AAAE Research Conference Proceedings.