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POGIL Among Other Instructional Strategies, Reasoning Abilities And Chemistry Students' Science Process Skills: A Comprehensive Review

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ABSTRACT

The objective of this paper is to review the connections between POGIL as an Instructional Strategy, Reasoning Abilities and Chemistry Students' Science Process Skills comprehensively. Process skills are skills which are transferable to everyday workplace challenges that require scientific skillfulness rooted in problem solving. The problem of poor academic performances among chemistry students at senior secondary school certificate examination is not unconnected to science students' weak science process skills. Chemistry students' poor academic performance creates a sensitive problem related to poor operational thought and lack of skillfulness among chemistry students for science students and educators. Thus the uninspiring teaching methods adopted by science teachers lead not only to poor academic performance in science but also incapacitating students from developing relevant skills necessary for creative thinking. Scholar pointed to the reality of poor response to Piagetian type tasks for measuring formal operational thinking among senior secondary school students -poor thinking/science skills- The questions which guide this review are: How can the problem of chemistry students' poor science process skills be resolved through the application of POGIL? How is POGIL connected to chemistry students' academic performance? And; What is the possibility that POGIL can serve as a bridge to fill the gap among different reasoning abilities chemistry students? These questions call for a comprehensive review of how POGIL can improve chemistry students' acquisition of science process skills; chemistry students' academic performance as well as bridging the gap among different reasoning abilities chemistry students. This review therefore examines how application of POGIL to teaching/learning processes may enhance the achievement of the desired learning outcomes. Although scholars have applied POGIL in numerous studies to examine the effect of POGIL on academic performance and academic confidence, however one of the findings of this review established that there is still a gap of literature review linking POGIL to formal thought dichotomy and science process skill acquisition.

Keywords: Academic performance, constructivism, cooperative learning, inquiry learning, instructional strategies, POGIL, science process skills, teaching.

INTRODUCTION

Science process skills are skills which are transferable to everyday workplace challenges that require scientific skillfulness rooted in problem solving. Science process skill, as "We Are Teachers" (Sept, 2011) states, is an intellectual activity usually done by scientists in solving problems and producing scientific products. Problem of poor academic performances among chemistry students at senior secondary school certificate examination is not unconnected to science students' weak science process skills. Meharunnisa & Hameed, (2016) opines that students and teachers in the educational sector are frustrated with poor learners' performance from elementary to higher level of learning.

Chemistry students' poor academic performance creates a sensitive problem related to poor operational thought and lack of skillfulness among chemistry students, for all stakeholders in science education. Njokwu & Eze-odurukwe (2015) suggests that Nigerian students' performance is very poor in chemistry over a number of decades at the senior secondary school certificate examination level. As suggested by De Gale & Boiselle (2015), learners demonstrated persistent difficulties inter-converting chemical knowledge through macroscopic, microscopic and symbolic form. This inter-conversion of chemical knowledge through macroscopic, microscopic and symbolic form requires science process skills in chemistry.

Scholars have carried out several researches (Oloyede 2012; Barthlow, 2011; Ogunleye & Bamidele, 2013; Ayuba, 2014; Erl, 2014; De Gale & Boiselle 2015; Njokwu & Eze-odurukwe 2015; Meharunnisa & Hameed, 2016; Utley & Calik 2016; Keller, 2017 and Bala, 2018) to detect the problem of poor academic performance. From scholarly findings (Barthlow, 2011; Ogunleye & Bamidele, 2013; Ayuba, 2014; Nnorom, 2015; Omokaadejo, 2015; Keller, 2017 and Bala, 2018), chemistry students' persistent poor performance is partly ascribed to inadequate teaching and adoption of ineffective instructional methods like lecture method which discourages students from constructing their own understanding. Thus the uninspiring teaching methods adopted by science teachers lead not only to poor academic performance in science but also incapacitating students from developing relevant skills necessary for creative thinking.

Scholar pointed to the reality of poor response to Piagetian type tasks for measuring formal operational thinking among senior secondary school students -poor thinking/science skills- (Gyuse, 1990; Oloyede, 1998; Demide, 2000; Oloyede, 2012).

Despite these concerns, application of rote learning and other traditional instructional methods is a norm. These chemistry students' poor science process skills is a problem which calls for a comprehensive review of how POGIL, a discovery learning instructional method rooted in problem solving phases, can improve chemistry students' acquisition of science process skills; performance in chemistry and possibly bridge the gap among different reasoning abilities chemistry students. This review therefore attempts to examine the possibility that teachers' application of POGIL to teaching/learning processes may enhance the achievement of the desired learning outcomes.

Scholars have applied POGIL in numerous studies like De Gale (2015) who examine effect of POGIL on academic performance and academic confidence. However, there is still a gap of literature review linking POGIL to formal thought dichotomy and science process skill acquisition.

THE REVIEW

THEORETICAL BASIS

Three main learning theories viz behaviorism, cognitivism and constructivism influences science educational pedagogy and several implications for teaching practices. Cognitivism and constructivism are the theoretical bases for this examination. The content of the topic is therefore a means of establishing theories linking science skills to improved academic performance through process oriented guided inquiry learning (POGIL) instructional strategy on one hand and using POGIL instructional strategy as a bridge between concrete and formal reasoning on the other hand.

Cognitivism is paradigm which proposes that the behaviour of learners is the result of his/her cognition and the main aim of education is to change learners' cognitive schemas. Jean Piaget is a leading cognitive psychologist who came up in the 1960 with a focus on the brain, playing a crucial role in advocating cognitivism. Jean Piaget emphasizes on two main functions: organization and adaptation. Organization implies that all cognitive structures are interrelated and any new knowledge must be fitted into the existing system. Adaptation is the

tendency of the organism to fit with its environment in ways that promotes survival. These gave rise to four-stage models of development known as Piaget's genetic constructivism (Piaget's theory of intellectual development) whose stages are: sensori-motor, pre-operational, concrete operational and formal operational stages. Between concrete and formal reasoning is termed as transition. Concrete, through transition to formal reasoning are the main focus of this work.
Lev Vigotsky introduces social constructivism in the 1970 which propose that social interaction with others is helpful to the learners in giving meaning to information. Thus in view of socio-cultural context as explained by Vigotsky, learners can develop certain level of meaning on their own; however, learners can grow even greater after interacting with classmates and instructors. By implication POGIL is model after social constructivism embracing small groups of students learning as a team. POGIL is also model after cognitive constructivism, a paradigm which consider knowledge to be constructed by either assimilation (incoming information is associated with the existing schemas) or accommodation (when incoming information does not match the existing schemas then it must be changed to accommodate this conflict). Another reason why POGIL is model after constructivism is that just as in POGIL, in constructivism paradigm, learners take control of the learning situations. Prominent pedagogical strategies emanating from this constructivism are project-based learning, discovery approach, problem-based learning and conceptual change method.
Discovery method is otherwise known as inquiry learning; POGIL is a type of discovery learning strategy. Discovery method itself is an offshoot of cognitive constructivism developed by Brunner. He advocates that the learner should play the role of scientist in the school laboratory, collect datum, analyze and arrive at a conclusion using scientific method. Constructivist based strategies and models like POGIL are known to be effective in fostering science skills through its cycles of activities.
The subject of review is therefore base on the highlighted learning theories.

CHEMISTRY TEACHER AND INSTRUCTIONAL METHOD

Method of instruction and direction of research in science, particularly chemistry are being affected by two tendencies explained by Desch (1925). On one hand, chemistry like any other science discipline is split up into a number of distinct specializations tempting /compelling researchers to confine themselves to a narrow field. Also, the boundaries between several sciences are becoming less definite through the development of border sciences, a new discipline in itself.
The dependence of the three branches of science, as far as it is possible to arrange the abstract in a linear series, chemistry depends on physics as the biological sciences in their turn depend upon chemistry (Desch, 1925). The theoretical part of each is built up on the established law of the preceding science base. This dependency of one science on the other follows the philosophic thought of reductionism which reduces chemistry to physics and assigned physics to be the paradigm science on the basis that the more mathematical a science is the better the science. This is a debatably subject in philosophy of chemistry. The dependence of chemistry on physics implies that theoretical advances in physics can bring about changes in method of practices and instruction in chemistry, thus chemistry teachers have to be insightful about theoretical advance in physics and it effect on selective instructional strategies in chemistry. The teacher is thus expected to be informed of evolving dynamism of scientific knowledge particularly in physics and chemistry. He is also expected to collaborate with physics and mathematics teachers as students' skillfulness in these subjects can affect chemistry teaching-learning processes.
The split in chemistry discipline is based on either the substances studied or the type of study conducted (Infoplease, n.d). The split up is given by the large number of branches of chemistry which are mainly reduced to five branches; these are organic chemistry, inorganic chemistry, analytical chemistry, physical chemistry and biochemistry. Chemistry can otherwise be broadly categorized as pure and applied chemistry. Other categories of chemistry are polymer chemistry, geochemistry and chemical engineering (Helmenstine, July 3, 2019). The split up in chemistry field is of paramount significance to how chemistry is introduced at secondary school level, as teaching process has to integrate and establish a balance between the different branches of chemistry. Therefore chemistry as a fundamental science subject taught in senior secondary school and beyond, chemistry teachers has to be responsible for inter-dependence of science subjects and the split up in

chemistry discipline.

CONCEPTS OF TEACHING

Teaching is the art of enlightening learner(s) or the public by a more knowledgeable person called teacher through a one on one interaction or teacher-learners interaction. Teaching can otherwise be seen as an interaction through selected medium/media, using relevant instructional resources and suitable approach to achieve a set of teaching\learning objective(s). Bichi (personal communication, 2017) defines teaching, as a bipolar process in which the more mature of the human society purposely, through pedagogical strategies monitors the intellectual development of the less mature to bring an all round development in him for the benefit of the society. Teaching can also be seen as a process of transferring knowledge from the one assumed to be more knowledgeable to the less knowledgeable in practical aspects of knowledge. It is an established process through which nations enshrine the development of their human culture, values and natural resources.

Teaching can be conceptualized traditionally or as a trending concept. The concept of teaching are examined through the spectacular views of different scholars. If teaching is seen as the process of imparting instructions to the learners in classroom situation then this conception is teacher centered where by the teacher gives information to learner(s) or the learners reads from textbook, watch/listen to video/audio while learning passively. This implies that knowledge and information are merely imparted.

From the trending definition of teaching, O2_introduction.pdf (n.d) views teaching as a process which cause the pupils to learn the desired knowledge, skills and also desirable ways of living in the society. B.O Smith's definition as cited in O2_introduction.pdf, teaching as a system of actions to produce learning, corroborates with O2_introduction.pdf view which describes teaching as a process in which learner, teacher, curriculum and other variables are organized systematically and psychologically to achieve certain predetermined goals. Other trending definitions of teaching as given by physicscatalyst.com (Feb 16, 2018) are as follow:

Dewey: Teaching is a manipulation of the situation where the learner will acquire skills and insights with his own initiation.

Morrison: Teaching is an intimate contact between the more mature personality and a less mature one.

Jackson: Teaching is a face to face encounter between two or more persons, one of whom (teacher) intend to effect certain changes in the other participant(s).

Hough & James: Teaching is an activity with four phases, a curriculum planning phase, lesson planning phase, an instructing phase and an evaluating phase. This is an organizational view of teaching.

Gage: Teaching is an interpersonal influence aimed at changing the behaviour potential of another person.

Clerk: Teaching refers to activities that are designed and performed to produce in students' behaviour.

National Teachers Institute (NTI) (n.d) also gave a number of teaching conceptualization by scholars thus:

Clark and Starr (1970:4): Teaching is an attempt to help people acquire some skills, attitudes, knowledge, ideas and appreciation.

Van Dalen & Brittel (1950): Teaching is the guidance of the pupils through planned activities so that they (pupils) may acquire the richest learning possible from their experiences.

Clark (1995): Teaching is the interaction between a teacher and student under the teacher's responsibility in order to bring about the expected change in the student's behaviour.

Basically, all the definitions highlights a common consent on the existence of the teacher, learners and instructional process directed towards specific objective(s). However, three definitions are of considerable importance. The definition of Hough & James is important because it breakdown the processes involved in organized form. The definition of Dewey is even more integrated in respect to the goal of science teaching as it points to a process which builds skills and insights on the basis of learners' knowledge and constructive strategies. Clark and Starr (1970:4) provides for the cultivation of scientific attitudes and appreciation (affective domain of knowledge). Most desirably, chemistry teaching should be carried out by teachers who are sound in content and practical aspects of chemistry; who know the quality of good teaching and who takes chemistry teaching as a profession and not a job.

Dewey's concept of teaching is strongly connected to teaching methods which establishes enhanced academic performance and acquisition of skills using constructive teaching strategies. This is important to science teaching because, science teaching is a complex activity that lies at the heart of science education vision (www.nap.edu, n.d). Science teaching/learning process requires a fundamental knowledge of nature of science. A fundamental reason for insight on nature of science, as Science Learning Hub (Oct 7, 2011) explains, is to help students think for themselves, construct their own explanations and reach their conclusions in ways that consider the scientific dimensions of socio scientific issues. Students who gains understanding of nature of science can connect science and the real world and apply science to daily problem solving situations. Such students can evaluate, think critically and operate on operations; Case & Griffin (1990) corroborates this view that science is a process of logical reasoning about evidence.

SCIENCE PROCESS SKILLS AND CHEMISTRY TEACHING/LEARNING PROCESS

If science process skills in science teaching can involve students in the behaviour and mental process that are characteristics of scientists (We Are Teachers; n.d), then science teachers and learners must be competently proficient in science process skills for successful outcomes in academic performance and in achieving the broad goal of science education. Mari (2016) suggests that an understanding of what science is and how scientists work is necessary for the teachers to help the pupils learn, teach them to reflect on the nature of science and ensure that learners are equipped with knowledge, skills and motivation to engage in fruitful scientific ventures. similarly, Science Learning Hub (Oct 7, 2011) opines that planning and teaching has to provide for nature of science, similarly science teaching should ensure that students are able to make informed decisions about issues, voice their opinions, take action and participate in decision making process of a democratic society.

As Duncan (September 28, 2016) explains, think about the activities of a science teacher; beyond simply helping students to understand scientific principles and theories, science teachers empower learners to think and solve emerging future problems. This is beyond memorizing, since Passionate science teachers create classrooms of discovery that model excitement for their field and learning. In view of this, Michael (1990) states that one of the most pervasive goals of schooling is teaching students to think. By implication, students who can think critically and solve problems can also monitor their own learning and as such can reason formally. These characteristics are qualities of individuals who have acquired science process skills. Formal reasoning skills and problem solving skills are strongly connected to chemistry students' academic performance. Oloyede (2012) links poor academic performance to lack of appropriate formal operational thought. From his findings, Oloyede (2012) also links formal thought with problem solving skills. Elkevbo Ed. (n.d), while explaining Bloom's taxonomy suggests that learning at lower level is to enable the building of skills in the higher level of taxonomy. Emphasis is on (top level taxonomy) higher order thinking like analysis, evaluation, synthesis and creation. By implication from Bloom's taxonomy, this is an underlying reason for a number of teaching strategies which tends towards skills development rather than content which is merely a vessel for teaching skills. Still, by implication, if one's thinking skills, problem solving skills, analysis, synthesis and creative skills which are put together science process skills are acquired, then formal reasoning skills is attained and the problem of poor academic performance in chemistry would be reduced drastically. Oloyede thus concludes that students who acquire process skills tend to think analytically and are more successful with new problems than those who do not possess process skills. Chemistry teaching is responsible for inculcating science process skills at lower level by using instructional methods which help learners to constructively develop higher order thinking or formal reasoning. Chemistry (science) teaching is equally critical in determining and applying instructional methods which research has shown to increase learning gains for concrete through transitional to formal reasoners.

INSTRUCTIONAL METHODS FOR CHEMISTRY TEACHING/LEARNING PROCESS

A number of instructional methods which can be use for chemistry teaching as suggested by Musa (2022) include lecture method, discussion method, demonstration method, problem solving method, discovery method, inquiry method, cooperative method, laboratory/experimental method, assignment method and project method among others. Of keen interest to this review are problem solving methods, inquiry method, discovery method and cooperative teaching approach.

Problem solving method is a teaching-learning process in which the students work on solving a problem by using the result of some analyzed data (PDE 103, n.d). The data are collected from a proven solution rather than assumed solution. In problem solving method, the students are given a problem and they are to find proven solutions to the problems. Approach to Problem solving method are three, these are:

- The Guided Approach: Inexperienced students are controlled and directed in every aspect of the lesson by the teacher using problem solving approach.
- The Modified Approach: used with students who are 'catching up' with the method and are capable of handling some of the procedures while the teacher remains the resource person.
- The Free Guided Approach: this is used with students who can follow procedures, formulate the topic and work it out to the point of generalization inductively or start from generalization, get to the point of formulating the topic deductively.

There are certain roles which the teacher assumes when applying problem solving approach, these roles includes the following:

He is to:

- Encourage the students' exploration and testing of new ideas.
- Encourage the students to prove and share the findings with other students
- Applaud creative and original work of any student.
- Guide the students to look for more ideas by raising questions.
- Summarize all the findings and announce it to the class; and
- Be in full control through the lesson

Problem Solving Approach

Advantages	Disadvantages
Students are actively involved in the lesson	It consumes time
The activities may generate enthusiasm and interest in the students	Slow students may be at disadvantage
Students are trained to organize their own learning	It may be too demanding on the teacher as students may discover series of facts and raise questions which may embarrass an ill prepared teacher
As students found things for themselves, the memory of what they learnt last longer	
The method encourages critical thinking and acquisition of science process skills	
They got to know new knowledge and the tentative nature of knowledge	The method is not applicable to all situations.

Inquiry (investigation) method is a scientific investigation used by students to arrive at a probable generalization as in problem solving method. Inquiry method is more or less the same as problem solving method because the two methods use the same scientific approach to investigate facts. The two are based on discovery method. Teaching concepts by discovery according to (PDE103) involves teaching a method of inquiry with broad application to problem solving and knowledge gathering. Problem solving is assumed to have come first as it was also assumed that students can begin to understand specific elements of the subject after learning how to solve problems and how to work with concepts and principles. The inquiry/problem solving method is better for the higher classes of senior secondary schools (SSS classes) while on the other hand the discovery method is suitable for all level.

Wolf & Fraser (2007) emphasizes the importance of group work and hands on activity; accounting for existing knowledge and building upon it; student conclusion with evidence and observation; encouraging students to share and discuss ideas with peers; the teacher guiding the students by challenging them to think beyond their current processes by offering divergent questions; the teacher facilitate appropriate discussion and help students to focus on experimental data and facts. These practices are collectively termed as inquiry based teaching and learning. In using the inquiry approach, the learners are expected to:

- ✓ Identify and classify the purpose of the inquiry;
- ✓ Formulate a hypothesis;
- ✓ Collect and analyze data;
- ✓ Test the hypothesis against the result of data analysis;
- ✓ Draws conclusions;

- ✓ Apply the conclusion to a new situation and new data; and
- ✓ develop a meaningful generalization

The scope of inquiry learning is to encourage active engagement, motivate learners, promotes autonomy and problem solving skills, -most importantly- to develop creativity and problem solving skills; and to tailor learning experience towards meaningful learning.

Discovery learning projects the belief that it is best for learners to discover facts and relationship for themselves (Davey 2017). "Discovery learning is an inquiry-based constructivist learning theory that takes place in problem solving situation where the learners draws on his or her own past experiences and existing knowledge to discover facts and relationships and new truth to be learned" (Davey 2017). PDE 103 (n.d) defines discovery learning method as a process through which students find out facts or knowledge through the understanding of concepts. This implies 'induction' whereby students proceed from specific examples (precepts) to concepts and from concept to generalization and principles. Three basic words are prominent in the discovery method; they are precepts, concepts and generalization. However, concept formation according PDE 103 (n.d) is the dominant activity in the method. Concept formation is therefore the difference between discovery method and inquiry/problem solving methods, though the three are interrelated.

Advantages of discovery method includes the below:

- ➢ The students discovers the facts on their own, hence it is self rewarding (they are being motivated).
- ➢ Students are actively involved in the lesson.
- ➢ The memory of concepts/principles last longer because they discover the fact on their own.
- ➢ Discovery learning helps students to understand the structure of knowledge (interrelatedness of the subject with other subjects)

The disadvantages of discovery learning are as follows.

- ➢ It is time consuming.
- ➢ Many instructional materials are required and this makes it expensive.
- ➢ It is not applicable to all situations.
- ➢ It is not possible to rediscover all knowledge;
- ➢ The teacher has to teach them some aspects of it at one time or the other.

The major theoretical perspective which underpins cooperative learning is motivational theory and constructivism. Olatoye, Aderogba & Anu (Nov 2011), defines cooperative learning as a teaching strategy in which small teams, each with students of different levels of ability use a variety of learning activities to improve their understanding of concepts.

Base on motivational theory which focuses on rewards and goal structures, cooperative goal structure create a situation in which the only means for group members to attain their personal goal is through the successful outcome of group work. An element of cooperative learning according to Olatoye, Aderogba & Anu (Nov 2011) is positive interdependence where students perceived that their success or failure is based on their working together as a group. Cooperative learning is built upon the works of educational psychologists, particularly those works that were based on constructivist theories of learning like John Dewey's theory of constructivism, J.S Brunner's discovery learning and Vigotsky's socio-cultural theory is among others theories which proposed that children actively construct knowledge in a social context. Cooperative learning is based on constructivism (constructed and transformed knowledge) by the students. Brandon (Jul 18, 2015), lists some pros and cons of cooperative learning which are hereunder given as advantages and disadvantages of cooperative teaching method.

Advantages of Cooperative Teaching Method:

- It creates higher level thinking skills due to the need for skill recognition and the presence of empathy.
- It creates new forms of individual responsibilities.
- It increases the level of personal participation in learning
- It boosts self esteem on various levels.
- As a result of the fourth point above, their problem solving skills can be enhanced.

Disadvantages of Cooperative Teaching Method:

- It creates a grading system which could be considered unfair.

- It creates new system of socialization structures that are not always beneficial.
- The above points may encourage students to stop trying with respect to their participatory effort.
- It places teacher's responsibility onto the learners.
- It creates a system of dependency.

POGIL AS INQUIRY BASED INSTRUCTIONAL STRATEGY

Curriculum reformers over the century have come to the conclusion that science teaching cannot be taught traditionally for successful acquisition of scientific knowledge. Their works on curriculum was greatly enhanced by the works of educational psychologists, particularly those works that were based on constructivists learning theories like John Dewey's theory of constructivism, Erik Erikson's theory of ego development, Jean Piaget's theory (1967), Bloom's theory on knowledge taxonomy, Brunner's discovery learning (1960) and Vigotsky's socio-cultural theory (1986) among others sought to establish critical thinking, develop inquiry learning, scientific metacognition and higher order thinking. In particular, the quest for science students to be proficient in science like knowing science, being able to give evidence to explain what they know/natural phenomena, solving daily problems, participating in community debates on scientific issues, being proficient in science process skills and having the right attitude towards science suffices the efforts of the educational theorists. The result of these works gave rise to the development of a large number of inquiry-based instructional packages whose effectiveness towards meaningful or permanent learning is still largely undergoing investigation. Such instructional approach includes Activity Based teaching approach, team teaching approach, 7E learning cycle, 4E learning cycle, 5E learning cycle, 3E learning cycle, Concept Mapping, Open Guided Inquiry Learning, Structured Guided Inquiry, Closed Guided Inquiry, and Process-Oriented Guided-Inquiry Learning among so many others. POGIL was basically developed for chemistry teaching, presently it application to science teaching is beyond chemistry teaching. As Pedagogy in Action (n.d) explains, POGIL was developed by a number of scholars which include Rick Moog, James Spencer, Frank Creegan, Troy Wolfskill, David Hanson, Andrei Straumanis, Diane Bounce and Jennifer Lewis among others.

POGIL AS AN INQUIRY INSTRUCTIONAL STRATEGY

Inquiry is one of the most important keyword with respect to the epistemological question of how the young ones, the learners and scientist come to understand the world. NPE, (2004) opines that one of the goals of science education shall be to cultivate inquiry, knowing and rational mind for the conduct of a good life and democracy. Science thrives on the inquiring nature of man irrespective of time and space; development of science will continue to thrive as a result of continual inquiring minds of scientists. Karadan & Hameed (2016) defines inquiry as the evidence based process that scientists engaged in to study and propose explanations about aspects of the natural world. When applied to students in science classrooms, inquiry learning generally indicates students' participation in activities and thinking processes similar to those employed by scientists, thus Akcay & Yager (2010), defines inquiry as an approach to teaching the acts scientists use in doing science which can be a highly effective teaching method that helps students to understand concepts and use of process skills. Inquiry method enables students to find the answers themselves.

The scope of inquiry learning is to encourage active engagement, motivate learners, promote autonomy and foster problem solving skills. In corroboration to this, Kaundjwa (2015), opines that inquiry instruction, which is characterized by an emphasis on problem solving, collaborative group work and critical thinking are learner centered compared to direct teacher instruction strategy. Sylvanus & Eke (2017) projects guided inquiry teaching method as a method of teaching which involves probing, finding out, investigating, analyzing, synthesizing, discovering, evaluating, questioning and thinking. Guided inquiry teaching method has been described as problem solving, critical thinking, reflective inquiry, deductive thinking and not mere assumption. These qualities are built based on the application of both basic and integrated science process skills.

Guided inquiry learning is one of the three types of inquiry learning classified by Chavel & Hart (2005), guided inquiry falls in the middle of inquiry instructional spectrum. This type of inquiry is commonly used when students are asked to make tools or develop a process that results in a desired outcome. If science is learned through sense perception, and it is empirical in nature, scientific investigations, including science teaching and learning can only be carried out through scientific methods by applying science process skills, otherwise described as the scientific method, scientific thinking, and critical thinking. That being the case, both science process skills and inquiry learning/teaching have the same goals. It can be stated that guided inquiry learning/teaching is a systematic method of fostering science process skills in teaching/learning process; therefore inquiry learning is fundamental to POGIL just as POGIL, when properly applied be instrumental in fostering science process skills among chemistry (science) students.

Karadan & Hameed (2016) avers that process oriented guided inquiry learning (POGIL) is an inquiry learning strategy that considers the nature and the outcome of science. POGIL materials are designed to operate through learning cycle based mostly on three phases of inquiry: exploration of a model, concept invention and application as shown by a number of literatures (Shawn & Susan, 2013; Meharunnisa & Hameed 2016; Walker &Warfa, 2017; and Keller, 2017). Walker & Warfa (2017) opines that students are opportune to engage in process skills above and beyond content and emphasize the process of integrating knowledge. In summary, POGIL sought to establish learners in creativity and problem solving skills and to direct learning experiences towards meaningful learning.

POGIL AS COOPERATIVE INSTRUCTIONAL STRATEGY

Social constructivism is a learning theory introduced by Lev Vigotsky in 1970. This theory is generally based on constructivism which proposes that knowledge is constructed through one’s own experiences and interaction with the outside world, thus the learner takes up active role in knowledge construction which facilitates the learning processes. Vigotsky social constructivism proposes that social interaction with others is helpful to the learners in giving meaning to information. He explains that learners can develop a certain level of meaning on their own but greater meanings can be attained through interaction with classmates and instructor. This socio-cultural context of constructivism is the basis for the development of a number of instructional strategies such as team learning, collaborative teaching and cooperative learning instructional strategies. Process-oriented guided-inquiry learning is a form of cooperative learning which applies team learning activities within groups of learners for greater learning outcomes. Karadan & Hameed (2016), projects that one of the two guiding principles incorporated in POGIL is cooperative learning principles. NPE (2013) recommends that cooperative work experience be encouraged to enable students have hands on experience of the skills they have learnt as well as experience the world of work which require cooperation for successful outcomes. From scholarly articles (Olatoye, Aderogba & Anu; 2011, Nnorome 2015 and Olatoye, Aderogba & Anu 2017), cooperative learning create positive interdependence, where students perceived that personal success or failure lies in their cooperation as a team. Hence to attain personal goals, learners will likely cooperate and carry one another along to succeed.

De Gale & Boiselle (2015) views POGIL as a collaborative learning strategy which employs guided inquiry within a cyclic system of exploration, concept invention and application. Shawn & Susan, 2013; Meharunnisa & Hameed 2016; Walker &Warfa, 2017; and Keller, 2017 are few among scholars who corroborated the three cyclic pattern of POGIL learning cycle. The design of POGIL learning cycle is such that brings learners together to carry out activities in science classrooms analyzing, communicating, controlling variables, coordinating, defining operationally, cooperating, experimenting, reporting, reasoning etcetera as a team with common, fears, hopes and objectives. In these activities, they acquire science process skills. They learn together how science and scientists work as they enjoy the fruits of discovery together and learn perseverance in areas of disappointment or when more critical thinking and more commitment is needed for complicated activities.

POGIL is a constructive inquiry and cooperative learning aimed at developing important process skills. POGIL lesson can be developed in a cycle of three phases (Karplus & Piaget 1980; Straumanis, 2010) of concept exploration, concept formation and application; or it can be developed in a cycle of five phases (Karplus & Piaget, 1980; Muhlenberg, 2011) made up of initiation, concept exploration, concept invention/formation, application phase and closure. POGIL activities are designed with stages that form the learning cycles. POGIL is exclusively known for its use of small groups in team learning, while development of knowledge content is attained through key process skills. The aim of POGIL lessons is therefore to develop those important process skills such as information processing, critical thinking, problem solving, oral and written communication, collaborative work, management, self assessment and metacognition.

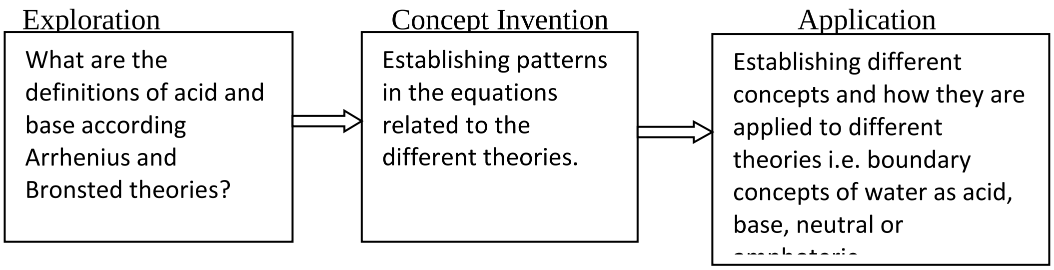

Fig 1 Three cycle model of POGIL

In the exploration stage, direct questions are being asked leading to convergent questions (Straumanis, 2010). This will trigger critical thinking; it may require facilitation of group discussions center around students' convergent views. Exploration leads to concept invention, facilitation is done inductively between exploration and concept invention, thus students begin to find patterns (for example relationship between Arrhenius acids & and Bronsted acid & base) emerging from their differences. In-class work groups in practical sessions can be organized. At this point, misconceptions diffuse leading to refinement and consensus. Between concept invention and application, facilitation is done deductively.

Application requires expert explanations which includes familiarization with expert terminologies; teacher's talk, mini-lecture and summary; reading textbooks on the topic and homework. These activities all together lead to reinforcement.

Muhlenberg (2011) illustrates a different model which includes orientation or engagement at the beginning and closure at the end, giving a cycle of five. At the orientation stage the students are being prepared, motivated and possibly, previous knowledge reviewed. At the point of closure, having applied the knowledge in exercises and problem solving, lesson closes by the students reflecting or assessing their performances and creating opportunities for corrections or revising through the preceding steps to attain the purpose of closure (self assessment and metacognition).

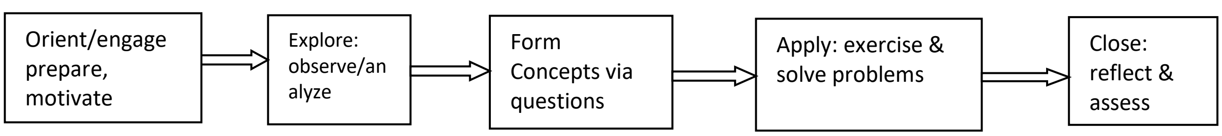

Fig 2: Five cycle model of POGIL

SCIENCE PROCESS SKILLS DEVELOPMENT AND POGIL

Educational scientists has the thrust to analyze, apply, explain and justify, scientific process skills with respect to the role it plays in science teaching/learning activities, scientific activities and daily life problem solving challenges. Thus Karadan & Hameed, (2016) opines that science process skills are becoming increasingly important as our knowledge base expands, as societies address interdisciplinary and more complicated problems and as businesses seek technological development on shorter and shorter time scales. In corroboration to this, NRC (2016) emphasizes the development of 'process skills' that would theoretically generalize one's thinking across the sciences and beyond.

Pedagogy in Action (n.d) explains that POGIL is a research based learning environment which engage students actively in mastering course contents and in developing essential skills by working in self managed teams on guided inquiry activities. Since it is both a classroom and laboratory techniques that seeks to simultaneously teach and impact key process skills such as the ability to think critically and work effectively as part of a collaborative team, in view of Pedagogy in Action (n.d), POGIL is therefore a unique strategy for developing process skills among chemistry students in particular and science students in general.

Michael, (1990) and Karadan & Hameed (2016), define science process skills as a set of broadly transferable abilities in new situations and more permanent in nature which is appropriate to many science disciplines and reflective of the behaviour of scientists. Such skills include making observations and measurement of natural phenomena, articulating hypotheses and designing and carrying out experiments. Mari (2016) includes process skills such as observing, measuring, classifying, experimenting, collection and interpretation of data, making models and operational definition among others as knowledge acquiring skills. Knowledge acquiring skills (cognitive skills) are otherwise known as process skills. In view of Michael (1990), scientific method, scientific thinking and critical thinking interchangeably describe the science skills.

Michael (1990) and Kimberley Scott Science (n.d) establishes that Science, A Process Approach (SAPA) classifies science process skills into two, viz: basic process skills and integrated skills. Basic process skills are six and they include observing, inferring, measuring, communicating, classifying and predicting. Integrated skills are the more complicated skills which according to Michael (1990) includes, controlling variables, defining operationally and formulating hypotheses, interpreting data, experimenting and modelling. Basic science process skills serves as the foundation on which integrated science process skills are pinged.

American Association for the Advancement of Science (AAAS) (1993) specifies the Benchmarks for scientific literacy in Project 2061 report as skills classified in the table below:

Table 1 Basic Process Skill Description

Basic process skills	Description
Observing	Use of five senses to derive characteristics of living things
Inferring	Explanation of observations and data
Measuring	Using standard and non-standard measures to describe dimensions
Communicating	Using words or symbols to describe an action object or event

Table 2 Integrated Skill Descriptions

Integrated process skills	Description
Controlling variables	Identifying variables, keeping variables constant or manipulating variables
Defining operationally	Stating how to measure a variable in an experiment
Formulating hypotheses	Stating the expected outcome of an experiment
Interpreting data	Organizing, concluding from data and making sense of data
Experimenting	Testing by following procedures to produce verifiable results
Formulating models	Creating a mental or physical model of a process or event.

Science is empirical because it deals with observable, measurable, testable and repeatable experimental evidences. From these analyses, science process skills can therefore be seen as the acquisition of sets of transferable and permanent proficiencies which scientists and science learners applies in carrying out empirical investigations (scientific inquiries) and scientific learning activities. POGIL is therefore an instructional tool which science teachers can use to develop chemistry students' science process skill acquisition.

POGIL, A BRIDGE FOR REASONING ABILITIES

Regarding reasoning ability, a worrisome issue which borders educational scientists as Chiappetta (1975) highlights, is that a great deal of subject matter taught in high school and college science courses is geared towards formal thinking, noting that these courses are not suited for concrete operational thinkers who probably represent the majority of students. Chiappetta (1975) opines that seemingly, curriculum developers need to develop science programs that are geared more towards concrete operational schemes than are the existing programs. Musa (2022) concludes that majority of the students in college-preparatory chemistry classrooms are concrete thinkers requiring specific learning cycle approach for effective instruction. This is not to say that didactic approach (talk and chalk method) which facilitate large amount of information to be presented within a short period of time should be ignored, because it enhances coverage of the syllabus. Huh (1981), made two conclusions from his research review viz:

- Concrete inquiry based instruction sequence is superior to formal expository instruction techniques in promoting cognitive development for concrete operational and formal operational students; and
- Concrete inquiry based instruction is more successful if concepts to be taught are more adaptable to the cognitive level of the students.

Since process-oriented guided-inquiry learning is a learning strategy which incorporates concrete procedures carried out by both concrete and formal reasoners under the watchful eye of the teacher, it is expected that the application of POGIL can bridge the gap between concrete and formal thought among science (chemistry) students in the sense that POGIL is a typical discovery/inquiry learning for which Brunner gave the advantages to include:

- Increased intellectual potency
- Shift from extrinsic rewards to intrinsic rewards
- Learning the heuristics of discovering is ascertain
- Conservation of memory is attained

Focusing on the impact of POGIL on the academic performance and acquisition of science skills of concrete and formal reasoners, Piaget (1985) enumerates the major tenets of POGIL as learning is enhanced when students: a) are actively engaged, b) are thinking, c) are analyzing data, discussing ideas, drawing conclusions and constructing their own knowledge and d) are interacting socially.

Piaget's work is of great significance to the development of science teaching strategies particularly, the application of POGIL to chemistry teaching. This is because teaching learners who are still at the concrete level requires that teachers organize their lesson such that learners are exposed to concrete materials and experiences for exploration such that learning goes from simple to complex. Once they master that stage, they can abstract concepts and develop skills for higher order thinking such as making hypotheses, designing experiment, drawing conclusion, generalization and application to problem solving situations. The design of POGIL as a strategy for chemistry teaching therefore is very suitable in bridging the gap between concrete and formal thought. One of the major conclusions of Huh, (1981) is that cognitive growth of hypothetic-deductive reasoning can be enhanced by a Piagetian experiment through the concrete-inquiry instruction model. Hence POGIL can lead to gain in cognitive growth of both concrete and formal reasoners.

OVERVIEW OF SIMILAR STUDIES ON POGIL, REASONING ABILITY AND SCIENCE PROCESS SKILL.

Several studies have been carried out by a number of researchers, establishing their similarities and dissimilarities.

A research work titled "The Relationship between Acquisition of Science Process Skills, Formal Reasoning Ability and Chemistry Achievement", was carried out by Oluafumilayo I. Oloyede (2012) in Bauchi state. The research questions are:

Is there a relationship between:

Students' formal reasoning ability and acquisition of science process skills?

Students' acquisition of science process skills and chemistry achievement?

Students' formal reasoning and science achievement?

The research employed comparative study research design, with a sample of three hundred and twenty (320) students from eight senior secondary schools. The instruments used to collect data are test of logical thinking, test of process skills and third term result from SSI examination in chemistry. The research employed product moment correlation coefficient for data analysis. The research findings are: a positive relationship exists between:

Formal reasoning ability and acquisition of process skills;

Formal reasoning and chemistry achievement; and

Acquisition of science skills and chemistry achievement

The research is relevant to this review because of its focus on chemistry students reasoning abilities and process skills; however Oloyede (2012) is not focused on testing the effectiveness of any strategy.

A study was carried out by Sen, Yalmiz & Geban (2015), titled the effect of process oriented guided inquiry learning environment on students' self-regulated learning skills, in Turkey. The study examined effect of

POGIL method compared to traditionally designed chemistry instruction (teacher-centered approach) on 11th grade students. Experimental groups were instructed with POGIL, while control groups received traditionally designed chemistry instruction. One of the research questions of the study is: are there any significant differences between the experimental group and the control group students' scores in terms of learning strategies (rehearsal, organization, elaboration, critical thinking, metacognitive self regulation, time/study environmental management, effort regulation, peer learning and help seeking)? The study employed non-equivalent control group design with two experimental groups and two control groups, randomly selected. The sample of the study is one hundred and fifteen (115) students from high school. It employed achievement goal questionnaire (AGQ) and motivated strategies for learning questionnaire (MSLQ) administered to both groups as pre and Post-test to determine students' regulated learning skills. MANOVA was applied for the analysis. The result indicates that POGIL improved student's mastery approach, task value, control of learning beliefs, self-efficacy for learning and performance, critical thinking, help seeking, peer learning, metacognitive self regulation, effort regulation and time/environmental management. The conclusion shows that POGIL was superior to the traditionally designed chemistry instruction on students' self regulated learning skills. By implication POGIL improved their potential for reasoning formally through equilibration. It has also demonstrated the use of POGIL in fostering science process skills acquisition. This work is important to this review because it highlights distinctive features which differentiate concrete and formal thought. By implication POGIL improved the potentials of concrete learners for reasoning formally through equilibration. It also demonstrates the use of POGIL to foster science process skills. The study however, did not specify the population of students from which the sample was drawn hence the scope of application in terms of generalizing the research outcome on specific population is limited and questionable.

Another study by Kaundjwa (August, 2015), titled Influence of Process Oriented Guided Inquiry Learning (POGIL) on Science Foundation Students Achievement in Stoichiometric Problem was carried out at the University of Namibia. It compared POGIL and traditional strategies to determine their effectiveness. The study applied a quasi-experimental non-randomized pre and Post-test control group design. Two intact science foundation classes were used as case study. The study employed ANCOVA for the analysis and the result indicates that there was a significant statistical difference in achievement. Unlike the interest of this review, effectiveness of POGIL on chemistry students' achievement was examined but science process skills and reasoning abilities was not part of the research variables but the result reveals that the POGIL group students were better able to give concrete reasons for the answers they had obtained through numerical calculations or multiple choices and demonstrated enhanced understanding of linking various stoichiometric concepts.

A dissertation work by Keller (2017), titled Impact of Process-Oriented Guided-Inquiry on Chemistry Students, was presented at Montana state university. One of the research questions is: how does the use of POGIL and inquiry-based laboratory activities affect students' development of reasoning skills? An unspecified research method was applied. The research is a classroom research which according to Keller is a way to explore new methods and because scientific control was unlikely to be possible, Keller used a larger pool of students for the intervention. The research methodology for the project received an exemption by Montana state university's institution Research Board and Compliance for Working with Human Subject. A sample of 37 students participated in the research. Keller (2017) adopted Lawson classroom test of scientific reasoning (LCTSR) (1978) to gauge formal reasoning skills. In determining Piaget's level of development, percentage was use to determine their placement based on their scores in Lawson Classroom Test of Scientific Reasoning. Standard deviation was employed in the analysis of other assessments. The results of the study are that the majority of the students in a college-preparatory chemistry classroom are in fact concrete thinkers; they require a specific learning cycle approach for effective instruction and the use of such instructions does not in itself contribute directly to their development of formal reasoning abilities. As a result the study points towards further work to incorporate elements of explicit instruction in formal reasoning skills. The work is relevant to this review because it involves POGIL and reasoning skills.

In the research work of Toyo, Aji & Sundaygara (2019), titled effect of POGIL model toward science process skills and physics acquisition of student, carried out in Indonesia, the objective was to determine the differences in the process oriented guided inquiry learning (POGIL) model toward science process skills and acquisition of students. The research employed quasi-experimental research design and involved the purposive sample of sixty-four (64) students. The Instrument consists of instrument for measuring science process skills and physics acquisition of students. The process skills assessment sheet is an instrument for measuring process skills. The statistical tool is two ways ANOVA, the finding shows that there were differences in science process skills between students who learned using the POGIL model and students who learn using the direct instruction model. There is an interaction between POGIL model and science process skills towards mastering of concepts. Like the interest of this review, Toyo, Aji & Sundaygara (2019) examine POGIL effective on science process skills.

Musa Hamdallah (2022) examined impact of POGIL on acquisition of science skills and performance in Acid-Base concepts among students of different reasoning abilities in Gwagwalada FCT Abuja. The study was carried out in Ahmadu Bello University Zaria. The study raises four research objectives two of which are to:

- Investigate the difference between the acquisition of science skills of concrete reasoners taught acid-base concepts using POGIL instructional strategy and concrete reasoners taught same concepts using lecture method; and
- Verify if there is difference in the acquisition of science skills of transition and concrete reasoners taught acid-base concepts using POGIL.

The research employed quasi experimental control group design using an accessible population of 5,566 chemistry students. Two intact science classes of ninety one (91) students were sampled using simple random sampling and stratified random sampling. Three instruments were used which are Acquisition of Science Skills in Acid-Base Concepts (ASSABC), Academic Performance in Acid-Base Concepts (APABCI) and Lawson Classroom Test of Scientific Reasoning (LCTSR). The statistical tools are Mean difference, t-test and ANCOVA. Some of the findings among others are:

- Concrete reasoners taught acid-base concepts using POGIL instructional strategy significantly performed better than those taught with lecture method
- POGIL enhances performance of concrete learners and promotes cognitive gains and deep comprehension among concrete learners.
- Transitional reasoners performed significantly better than concrete reasoners when taught acid-base concepts using POGIL instructional strategy, however the two groups made gains in academic performance.
- The hypothesis which states that the extent to which the acquisition of science skills of transition and concrete reasoners taught acid-base concepts using POGIL is not significantly different is rejected. However, the POGIL treatment led to an appreciable gain in the acquisition of science process skills of the two groups.

Conclusively:

- POGIL enhances performance of transition and concrete learners and promotes cognitive gains and deep comprehension among transition and concrete learners.
- a positive relationship exist between reasoning ability and academic performance on one hand and an even stronger correlation between reasoning ability and acquisition of science process skills after POGIL treatment on the other hand.

This research is quite important to this review because it captures relevant concepts reviewed in this article which are POGIL, reasoning abilities and chemistry students' science process skills, it is also important because it embraces all the major review in this article in it literature.

IMPLICATIONS OF THE REVIEWED LITERATURE

Several studies has been reviewed, some of which test the effectiveness of POGIL on process skills, academic performance, reasoning ability or test the effectiveness of POGIL on two of these variables. There is however, a dearth of studies covering POGIL effectiveness on process skills, academic performance and reasoning abilities in one work and hence the need to bridge the gap in this review. The implications of the studies reviewed on the present review are thus explored.

Oloyede (2012) is important to this work in the sense that it similarly studies relationships between formal reasoning, science process skills and achievement (academic performance) in chemistry. The research attributes poor performance in chemistry to lack of appropriate formal operational thought in the students. The research further explains that students equipped with science process skills tend to achieve higher than students with low process skills. Although the research suggests that chemistry teachers should engage students maximally with activities that could help them develop the spirit of inquiry through their exploration of nature from their local environment, the research is not about suitable instructional strategies. It is arguable that if students have attained formal operational thought, then they have acquired critical thinking skills and can transfer learning to resolve other problems, in other words they have acquired process skills otherwise described as problem solving skills. It follows therefore that even with traditional strategies, meaningful learning can take place. The last phase of the five phases of learning in five phases of POGIL design is to close through reflection, evaluation, assignments, reading of text et. Cetera. This is aimed at developing metacognitive self assessment spirit. A metacognitive learner is a formal learner and POGIL is designed to embrace concrete, transition and formal reasoners. Oloyede's work is therefore a source of information enrichment for this review.

The work of Keller (2017) is of great implication to this review by virtue of a number of literatures which it reviewed. He cited two works, one (the POGIL Project 2012-2016) of which found significant improvement in achievement and the other one (Chase, 2013) found no significant improvement in achievement with the use of POGIL in addition to some studies which found no significant improvement in achievement with the use of POGIL. This information is relevant as he pointed out the possibility that for formal reasoners who have attained equilibration and are metacognitive learners, the use of POGIL might not really make any significant difference. His work has therefore give definition to the application of POGIL as a means of closing the gap between concrete and formal operational reasoners. The irregular research method makes the study ambiguous and this ambiguity is also seen in the analysis and interpretation of data, this is because the research is an action research. The researcher states that the sample isn't large enough to be able to perform a reliable statistical analysis though he applied standard deviation. He accepts that there are so many other factors which may have played a part in determining their scores, this is doubtful however. The implication is that the research outcome may not be reliable. Furthermore his adoption of a standardized instrument: Lawson classroom test of scientific reasoning (LCTSR) (1978) to gauge formal reasoning skills is an eye opener to grouping experimental group into subgroups base on the instrument for gauging reasoning abilities.

Musa (2022) has a great and unique implication on this review for it capturing of all the variables of this review on one hand and on the hand, the work embraces the literature reviewed in this review extensively. Musa (2022) is therefore a great source of enrichment in terms of literature and findings on all the variable of interest.

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