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Inquiry-Based Experimental Design for Enhancement of Teaching and Learning of Chemistry Concepts

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Abstract

Chemistry concepts to be well learned by students, there might be a conducive learning environment and this is due to the approach employed by educators. This review then is about inquiry-based experiment design as an innovative teaching and learning tool that enhances chemistry instruction. By collecting all related kinds of literature, we used Google Scholar, ERIC, and Web of Science database. The conclusion of this literature review revealed that effective implementation of inquiry-based experiment design enhances the teaching and learning of chemistry concepts. It is also recommended that chemistry educators could be trained on the professional use of the approach for the good classroom implication and students' understanding of the concepts learned. Further studies should focus on the use of inquiry-based experiment design in the teaching and learning chemistry concepts.

Keywords: inquiry-based learning; chemistry education, constructivism

Introduction

Students in the 21st century have developed up in a fast-paced world of concrete from abstract where the teacher was seen to be the overall of the process (Kivunja, 2014). As educators, we could ensure that learners are equipped with the necessary skills and competencies that empower them to succeed in the global market. Learners do not need knowledge but they need skills to apply that knowledge to meet real-world problems (Velden, 2014). Students who develop an even larger set of competencies will be at an increasing advantage in work and life (Hysa, 2014). Our learners will become future scientists, researchers, leaders, and thinkers of our world, to achieve this they need quality and applicable education that give them the diverse skills they might need for success, Barkatsas and Bertram (2016) and which may boost their discoveries while performing experiences (Sibomana et al., 2021).

Education systems that rely largely on digestion and reproduction of subject content have not produced the desired results. In place of feeding student's ready-made knowledge,

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student-oriented approaches that emphasize how and where to find and use knowledge have become more prominent (Alkan, 2018). Inquiry-Based Learning (IBL) is a multifaceted activity that guides learners to inquire or generate meaningful questions that lead to the relevant answers (Ismail & Elias, 2014). Thus, the current research looks at the goals, characteristics, and outcomes of the inquiry-based learning method for enhancement teaching and learning chemistry concepts.

Although the inquiry-based learning method has only been introduced recently, it has become one of the most popular learning methods in the developed countries such as the USA and Canada. In Malaysia, it is yet to be introduced (Ismail & Elias, 2014). However, some related classroom methodologies, such as problem–based learning method, has been practiced. In the learning of science subject, through observational, experimental, and practical activities, chemistry subject is seen to be more understandable (Yitbarek, 2012). The traditional method of chemistry teaching does not stimulate students' interest and result in poor performance in chemistry (Ibrahim, Hamza, Bello & Adamu, 2018). Since practical activities are vital in teaching and learning chemistry as they stimulate students' comforts and enthusiasm, they also enhance students' critical thinking and problem-solving skills by promoting scientific habits of minds (Hofstein & Mamlok-Naaman, 2007). According to Trna and Trnova (2012) the incorporation of Inquiry-Based Science Education (IBSE) to connectively improve students' understanding of sciences engages them in the investigative nature of science and helps them put materials into meaningful context and improve students' critical thinking; hence developing positive attitudes towards chemistry and other science subjects. IBL enables learners to be more active and be able to engage themselves in laboratory activities and this will now enhance teaching and learning of chemistry concepts. According to Chairam, Klahan and Coll (2015) IBL is student-centered learning looked to help students enjoy activities and become interested in learning chemical kinetics. IBL increases students' interest and encourages them to get an understanding of chemical phenomena (Hofer, Abels, & Lembens, 2018).

Literature review

The process of inquiry begins with constructing and gathering information and data through applying the human senses (Ismail, 2014). The inquiry-based instruction is principally very closely related to the development and practice of thinking and problem-solving skills (Dostál, 2015). The inquiry also is viewed as a process of understanding the characteristics of science through scientific experiments. In short, Inquiry is about the development of critical thinking that can lead to a problem- solving.

Inquiry-based learning is an educational strategy in which students follow methods and practices similar to those of professional scientists to construct knowledge (Pedaste et al., 2015). From this, students get time to think about what they are doing and motivate them since they have contributed to the development of the lesson. Bruner argues that through the experiment for oneself to discover and acquire more information in the way that makes the information clearer for problem-solving, thus, the philosophy of Bruner shows that we should learn by doing (Bruner, 1961).

In inquiry- based pedagogy learners are interested in how knowledge is generated and transmitted and how they can acquire the knowledge and skills necessary to become life-long learners (Ismail, 2014). Therefore, instructors have started to look at the goals, features, and results of the inquiry-based learning method that can provide a thinkable and better alternative. According to Hofstein and Mamlok-Naaman (2007) scientific inquiry is a procedure whereby scientists explore the problem, conduct scientific investigations, collect and analyses relevant data and then summarize the obtained results before reached conclusions are communicated. Similarly, according to the Center for Science Mathematics and Engineering Education (2000) inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results.

Classification of inquiry pedagogy

Inquiry is a very wide concept when used in the context of teaching and learning. Researchers have tried to make a classification of inquiry-based activities depending on the levels of student participation and teacher participation. They generally argued that inquiry can be classified as guided, structured, coupled, and open inquiry as according to Anderson (2001); Aulls, et al. (2015); Bolthe and Rauch (2014); Hofer and Lembens (2019); Khalaf and Zin (2018) and Martin-Hansen (2002) open or full inquiry is defined as a student-centered approach that begins with a student's question, followed by the student (or groups of students) designing and conducting an investigation or experiment and communicating results, it also requires higher-order thinking, and usually, students work directly with the concept and materials, equipment, and asking the questions that guide their investigations is the key to open inquiry. Also, having students ask the questions that guide their investigations is the key to open inquiry since it requires higher-order thinking and usually has students working directly with the concept and materials, equipment, and so forth. Students devise a plan using material provided or approved to gather on their own, carry out their investigation, and record their data. Once the study is done, the data are analysed with the class ready to give disapproval, make a claim grounded on their information, sharing the processes and outcomes.

Guided inquiry involves teacher preparation of inquiry question and students taking opportunity to carry out investigation of those questions, then after the students under the guidance of the teacher design a process to reach their own conclusion and it turns into open inquiry and students and teachers have to seek data from various sources to use in investigation while coupled inquiry is a type of inquiry-based learning that put together both a directed inquiry examination with an open-inquiry examination whereby through the beginning to an invitation to inquiry along with the directed inquiry, the teacher picks the first question to explore, precisely pointing a specific standard or benchmark, this method of directed inquiry followed by open inquiry outcomes in student-generated questions that strictly relate to the standard or benchmark from the first study. Specific ideas can be delved into a more didactic style permitting students to link their concrete experiences to abstract concepts, comparable to a learning sequence.

The same authors, define structured inquiry or simply directed inquiry as an instructional strategy which is mainly carried out by the students following the teacher's instructions at every stage of the inquiry learning cycle, in this type of inquiry the student's engagement in the process is only limited to the teacher's instructions. These forms of inquiry-based learning are summarized in Figure 1.

Figure 1: Forms of inquiry-based learning (Adopted from Martin-Hansen, 2002)

An overview on Inquiry-Based Science Education (IBSE)

Inquiry-Based Science Education (IBSE) is a form of learning where teachers provide evidence and students get an opportunity to explore, experiment, ask questions, and develop responses based on reasoning (Riga, Winterbottom, Harris, & Newby, 2017). IBSE has been promoted as an effective way of teaching and learning science by engaging students in designing and conducting their scientific investigations (Van-Uum, Verhoeff, & Peeters, 2016).

The research showed that IBSE increases girls' participation in science among Sub-Saharan countries (Igrecio, 2011). According to Duran (2016) IBSE increases students' critical thinking in science. The use of IBL in teaching and learning has positive implications as it helps students to boost their conceptual understanding in motion and force (Fan, 2015).

IBL learning is an effective method that helps the pre-service teacher to improve teaching and learning science related subjects, Leavy, Hourigan and McMahon (2010); for example, the teaching and learning of biology by using material-oriented towards inquiry-based learning helps students to understand biology concepts (Damopolii, Nunaki, Nusantari, & Kandowangko, 2018). The inquiry learning cycle is presented in Figure 2.

Important Characteristics of Classroom Inquiry and their Differences

Human beings are born to question. We are born to ask why. Inquiry begins with acquiring data and information through interactions with our environment. Stimuli provide us with information, and we ask questions to make sense of it all.

As described in Table 1, Inquiry-based teaching and learning occurs when students' experiences are described by the essential features, listed in the left-hand column. However, students rarely can begin here. They first have to learn to ask and evaluate questions that can be investigated, what the difference is between evidence and opinion,

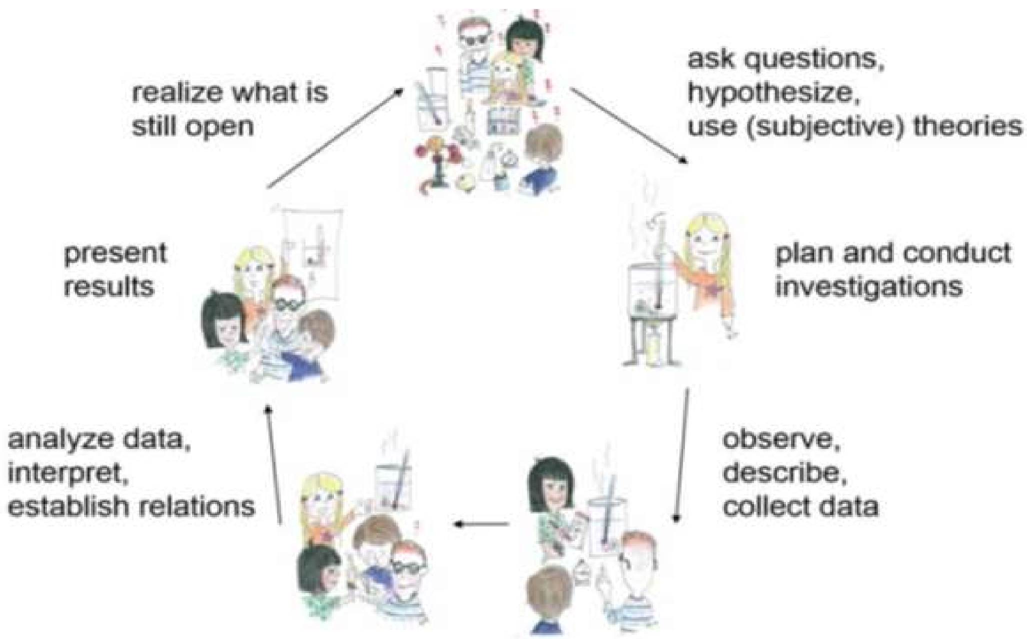

Figure 2: Inquiry learning cycle

(Adopted from Lembens and Abels, 2016, p.2545

Unfortunately, traditional educational offerings often work in ways that discourage inquiry and limit students' innate curiosities. This stifling of a student's need to know has served to **shift the focus of today's educational system from inquiry to assessment**. The shift has manifested in classrooms filled with students less likely to ask questions and more likely to be told what to learn and what questions to answer. Memorizing facts to help answer questions is an important skill for students to master. Inquiry, however, is a skill that will lead students toward being prepared to enter a workforce that is placing increasing emphasis on creativity and problem-solving (Lembens and Abels, 2016). Table 1 describes essential features of classroom inquiry.

how to develop a defensible explanation, and so on. A more structured type of teaching develops students' abilities to inquire. It helps them learn how to determine what counts. The degree to which teachers structure what students do is sometimes referred to as "guided" versus "open" inquiry.

Table 1 Important characteristics of classroom inquiry and their differences

Essential feature	Differences			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in questions provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in the development of communication	Learner provided broad guidelines to use sharpened communication	Learner given steps and procedures for communication

(Adapted from Martin-Hansen, 2002)

Methodology

To answer the research objective which was about to know what are the contributions of IBL toward teaching and learning chemistry; we conducted a literature search to collect all related kinds of literature about Inquiry-Based experimental design of chemistry learning. Google Scholar, ERIC, Web of science, and related Websites were used as the database. During searching inquiry, chemistry learning, the experiment was used in combination as the keyword to search journals, books, and websites to be used in this research. 56 studies were obtained, some of them were not related to our investigation and which did not answer the research question were excluded, we remained with 37 studies where their selections were based on year of publication, and language. These studies were published between 2010 and 2021 and must be published in English.

Finding

The result of this study discovered that Inquiry-Based Experimental Design augments students' conceptual understanding of chemistry concepts and inspires the motivation of students in chemistry. The research conducted by Szalay (2015) about promoting inquiry-based teaching of chemistry subject, in which 118 in-service teachers have participated and requested to design their instructional materials among which 70% were inquiry-based resources. This study was used only as a pilot study, the result revealed that the use of inquiry-based activities promotes students' cognitive skills in chemistry. Furthermore, the research conducted by Nedungadi, Malini, and Raman (2015) about Inquiry-Based Learning Pedagogy for chemistry practical experiments using OLabs by employing three modes of inquiry learning namely structured, guided, and open inquiry-based learning in line with the Indian Central Board of Secondary Education (CBSE) goal of nurturing higher order inquiry skills for student-centered and active learning; had discovered that inquiry-based OLabs pedagogy empowers the teachers to provide differentiated instruction to the students and enhancing students' interest and motivation in teaching and learning acids and bases. In addition to the above, all forms of inquiry were analyzed and revealed that in structured inquiry based on the analysis and data recorded students can identify which samples are acids and which are bases and then compare their conclusions with the observations and inferences given in the procedure tab. In guided inquiry, based on the analysis and data recorded, students can identify which samples are acids and which are bases but make their conclusions. In open inquiry, based on the analysis and observations students can identify which substance is used in car batteries which one is used in soaps, detergents, and cleaners.

The study conducted by Aulia, Poedjiastoeti, and Agustini (2018) about the usefulness of directed inquiry-based learning material on students' science reading ability, in a research which was focusing on the execution of guided inquiry-based learning material on solubility and solubility product concepts, the participants were 20 students who are in 11th graders from four selected high school in the academic year of 2016/2017; both experimental and control groups were used, the N-gain calculation data were then transformed on the basis of validity, practicality, and effectiveness. The result showed that the enlargement in N-gain score exhibited that application of established learning material through guided inquiry learning can improve students' science literacy skills. The increase of N-gain score occurs because the teacher who has been performing all phases of guided inquiry learning implemented in well to excellent category. It means that guided inquiry-based learning material on solubility and solubility product (Ksp) concepts can improve the students' science literacy skills in all aspects of attitudes.

The research by Juntunen and Aksela (2013) about Life-Cycle Analysis and Inquiry-Based Learning (LCA-IBL) in chemistry teaching revealed that LCA-IBL approaches should be implemented into chemistry education at all school levels since LCA-IBL helps learners being more active and foster their critical thinking skills, problem-solving and scientific literacy.

The study conducted by Ural (2016) about the effect of the directed inquiry laboratory experiment on science education students' chemistry laboratory attitude, anxiety, and achievement where participants were 37 third-year undergraduate students to determine the density of the liquid, separating mixtures by using the difference in their boiling point, display law of constant proportion in MgO, comparison of different metal oxidation tendencies, creating FeS compounds, preparation of solution with desired concentration and production of aspirin. The finding showed that there was a significant increase in students' laboratory attitude and achievement toward chemistry. Another research was conducted by Wildan, Mataram, and Hakim (2019) about the Stepwise Inquiry Approach to Improving Communication Skills and Scientific Attitudes on a Biochemistry Course. The effect of stepwise inquiry implementation was analyzed and found that the classes implementing stepwise inquiry had higher scores for communication skills and scientific attitudes than those undertaking expository approaches. The implementation of stepwise inquiry significantly affects the scores of scientific communication and attitude skills based on MANOVA analysis. The involvement of students independently in the investigation process increases their ability to construct knowledge and build arguments, in addition to increasing their motivation for learning. This established motivation enables the formation of positive attitudes, such as scientific attitudes among students.

According to Cheung (2008) science teachers generally find inquiry-based laboratory work very difficult to manage, his research was aimed at facilitating chemistry teachers to execute inquiry-based laboratory work in Hong Kong secondary schools. The main concerns of seven chemistry teachers were recognized. They were mostly bothered about the lack of class time, scarcity of effective instructional materials, and the need to teach large classes. To reduce teacher worries, teaching strategies were developed to help them. The strategies consist of the use of guided inquiry rather than open inquiry, the development of ten examples of authentic inquiry, and the inclusion of student oral presentations as a key component of the inquiry process. Trials done in schools showed that these strategies are beneficial.

The study conducted by Juniar, Silalahi, and Suyanti (2018) about the development of Science Process Skill for Chemistry Teacher Applicant Through Analytical Chemistry Learning with Guided Inquiry-Based and eXe Media, in this study 40 participants were divided into two classes A and B (experimental and control group) of 20 students in each class, the topic under study were gravimetric and titrimetric. The finding of this study revealed that the use of Guided Inquiry-Based and eXe Media increases communication, planning experiments, measuring, use tools and materials in analytical chemistry. Another study conducted by Shamsudin, Abdullah, and Yaamat (2013) about strategies of teaching science IBSE by novice chemistry teachers revealed that the inquiry-based teaching strategies were able to stimulate excitement among students when learning science, likewise, a study by Jack (2013) reported concept mapping and guided inquiry as an effective techniques for teaching difficult concepts in chemistry, the study was investigating its effect on students' academic achievement, it employed 251 senior three secondary chemistry students from three senatorial districts of Taraba state.

According to Bilgin (2009) students had a better understanding of acid and bases concepts and a more positive attitude toward guided inquiry instruction. Furthermore, the study conducted by Stout (2016) on open inquiry-based on carbon dioxide (CO_2) experiment, has shown that students enjoy this experiment and learn from it, also instructors' observations indicate that even several semesters after taking this laboratory students tend to work more independently in the laboratory and are more deeply and intellectually engaged in the experiments.

In their study, Leonard and Nwanekezi (2018) employed a quasi-experimental research design to investigate the effectiveness of guided inquiry and task hierarchy analysis model in cooperative learning strategy on chemistry students' performance; after analysis, they recommended that Guided Inquiry Learning Strategy (GILS) and Task Hierarchy Analysis Model (THAM) in Cooperative Learning Strategy (CLS) should be putted into practice by chemistry teachers to teach acid-base reactions to enhance students' performance and retention in Chemistry, this recommendation was based on the findings where the pre-test mean performance of the experimental group taught using THAM in the cooperative learning strategy was 13.96 while their post-test mean performance score was 21.10. The same findings showed that students from the control group taught using the lecture method, scored 12.92 in the pretext and 14.76 in a post-test which indicated that the difference between the pretest and posttest mean performance of the experimental group and the control group were 7.14 and 1.84 respectively. This served as evidence that THAM in cooperative learning strategy has a greater effect on the mean performance of students in acid-base reaction than lecture method. Besides, Wheeler and Bell (2012) demonstrate that students are more engaged and take ownership of the activity as well as the content in an open-ended inquiry. By using the simple strategies for scaffolding inquiry, teachers can incorporate inquiry into their chemistry instruction throughout the year and with investigations, they are already using.

Conclusion and recommendation

The usefulness of the learning model is strong-minded by the ways students' creativity and interest were influenced. Inquiry-based experiment design has been proved to enhance the teaching and learning of chemistry concepts in case it is professionally implemented. Using a less precise model of learning may hinder students' understanding of the concepts and cause them to be less motivated to learn the subject. Thus, a model of learning such as inquiry-based is strengthened by the active participation of all students since it is a learning that requires them to solve problems through investigation activities which increase their understanding by linking new information with previous cognitive structure resulting in meaningful learning.

Science educators and especially chemistry teachers should be trained on the effective implementation of inquiry-based experimental design with its different learning models as to be equipped with different technic and strategies to facilitate learners and stimulate their intention to know. Further studies in different settings should focus on the classroom implementation of inquiry-based experiment design as an innovative teaching approach that enhances chemistry instruction.

Conflict of Interest

The authors declare that they have no conflict of interest.

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