Strategies of Teaching Science Using an Inquiry Based Science Education (IBSE) by Novice Chemistry Teachers

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Abstract

Teaching Science is not about preparing students for a world that is static and fixed, but it concerns getting students ready to cope with changes and challenges in their lives. Traditional direct instruction in Science generally focuses on mastery of content with less emphasis on the development of scientific skills and attitudes; students are the receivers while the teacher is the dispenser. In most classroom contexts, teachers are preoccupied with academic activities in pursuit of the schools’ successes; often in the form of their students gaining as many A’s as possible. This scenario does not help students learn in a meaningful manner. This study specifically examines how meaningful science learning could be achieved via the introduction of an inquiry-based Science teaching approach. Three trainee teachers who underwent their teaching practice in Semester 2 2011/2012 session participated in the study. The study employed qualitative research design whereby data were mainly obtained through interview and document analysis in the form of lesson plans and reflective journal. Occasional observations on the way the trainee teachers apply the inquiry-based teaching strategies and model exposed to and taught in the Science Teaching Method course they took in the previous semester were also noted. The findings revealed that the inquiry-based teaching strategies employed were able to stimulate excitement among students when learning science. The ZYL teaching model was also proposed at the end of the study. This proposed teaching model summarizes the strategies of inquiry discovery in Science Education that can be adapted in science teaching process.

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Keywords: Science teaching, Inquiry, IBSE, teaching strategies

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1. Inquiry-Based Science Teaching

The term ‘inquiry’ generally signifies the process of acquiring or obtaining information by investigation, often personally and voluntarily carried out by the person who is eager to know the phenomenon in question. Hiang’s (2005) elaboration of inquiry includes investigation of a problem; finding truth or knowledge that requires thinking critically, making observations, asking questions, doing experiments and stating conclusions; and thinking creatively and using intuition. There are three mediums in inquiry-based science teaching method, namely inquiry, discovery and experiences (ibid.). Inquiry is a process of understanding the characteristics of science through scientific experiments. It is through try outs, testing and further information search that individuals begun to see patterns or connections, often leading to discoveries. Discovery purposes to obtain knowledge, concepts and generalization. Meanwhile, experiences serve as the core in which both inquiry and discovery processes occur whilst simultaneously allowing the development of science process skills and fact gathering to take place. Aksela et al. (2010) elaborates the importance of competencies enhanced through IBSE (Inquiry Based Science Education) which are decision making, critical thinking, adaptability, tolerance and autonomy. This undesirable of teaching method should not be at the cost of transformation in learning or finding that science education is an entirely different activity from their earlier experiences whether from primary school or previous science teacher. This transitions from old tradition to new need a scalar to be measure to unsure the differences among those to method. Franklin (2002) elaborates those two methods as below:

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Inquiry-Based</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle Learning Theory</td>
<td>Constructivism</td>
<td>Behaviourism</td>
</tr>
<tr>
<td>Student Participation</td>
<td>Active</td>
<td>Passive</td>
</tr>
<tr>
<td>Student Involvement in Outcomes</td>
<td>Increased Responsibility</td>
<td>Decreased Responsibility</td>
</tr>
<tr>
<td>Student Role</td>
<td>Problem solver</td>
<td>Direction follower</td>
</tr>
<tr>
<td>Curriculum Goals</td>
<td>Process oriented</td>
<td>Product oriented</td>
</tr>
<tr>
<td>Teachers Role</td>
<td>Guide/facilitator</td>
<td>Director/ transmitter</td>
</tr>
</tbody>
</table>

2. Traditional Science instruction vs. Inquiry instruction

This review of literature aims to examine the advantages and disadvantages of inquiry teaching and traditional science instruction, and to discuss the various teaching strategies within the inquiry-discovery approach. Many researchers acknowledged the benefits of using inquiry-based teaching methods; students learn best when they take an active role and practice what they have learned (Smart & Csapo, 2007). Other benefits of IBSE include improving students’ attitudes towards science and enhancing interest, curiosity and liking for the subject. The traditional, direct-teaching approach has long been criticised for causing students’ dislike for science, largely due to boring presentations, too much writing, too little practical activity and too much whole class teaching where students are simply recipients of information. Nonetheless, researchers have also pointed out that teachers employing inquiry-discovery approach should first scrutinize classroom organization to ensure the seating arrangement helps ease children’s transition from one activity to another. Connecting one activity with another is critical especially if the aim is to enable students see relationship between concepts. Failure to connect the relationship between and among concepts will generally result in students understanding related phenomenon in isolation.

Teachers using inquiry-based instructions also include more hands-on activities (Poon, Tan & Tan, 2009), with the teacher playing the role of a facilitator. Studies conducted on teachers’ role during inquiry-based teaching revealed most teachers found interacting with students rather daunting (ibid.) They encountered difficulties in channelling and maintaining the students’ interests as the students engage in inquiry activities...
The struggle to communicate and to capture interest is an indication of unpreparedness among science teachers for the social demands of inquiry-based teaching (Oliveria, 2009); hence if such case happens, the teachers need to be specifically trained in methods that will enhance their abilities to use directives in a polite form and to strategically share authority with their students while concurrently upholding authority in the classroom. This would call for careful planning. Careful planning and preparation is also required for adequate content information to be imparted to students, which makes it difficult for some science topic to be taught using the inquiry method (Robertson, 2007).

Due to the need for thorough preparation as well as the uncertainty of in-class activities based on students’ response, most teachers tend to resort to the more structured and organized ways of teaching (Qablan et al., 2009). Through direct instruction, teachers can minimize the difficulties of having to keep students motivated if they were to be left on their own to acquire knowledge through inquiry-based learning (Bencze, 2009); it is easier for teachers to assist students with a step-by-step guide to acquire content rather than letting them do the activity on their own and get confused. In fact, many researchers advocated planned experiences in science for children rather than incidental ones using inquiry method (Mason, 1963). The direct instruction approach is also considered the best teaching method for learning content and new skills. Nevertheless, direct instruction also has its limitations. There is a tendency that direct teaching restricts the development of students’ process skills and abilities to make judgment (Wang & Wen, 2010). This is especially true if students resort to memorizing information given due emphasis by teachers during science lessons, as well as when the teacher poses a problem and then solves it without allowing opportunity for the students to discover. Direct instruction too works best only if the teachers possess strong working knowledge pertaining to both current scientific content and pedagogical savoir faire. Those without may find it difficult to provide clear explanation of concept while addressing students’ ability and opportunity to understand. The tendency is that direct instruction approach does not foster development of students’ scientific attitude.

The above comparisons provide sound reasons for teachers to adopt the inquiry approach to teaching science instead of direct instruction. It is apparent that the inquiry–based approach benefits students: they gain better understanding of content, ability to think critically and creatively (Wang & Wen, 2010) and enhanced problem–solving skills. Meanwhile, the teachers’ skills and knowledge also expand as they engage in activities to improve their ability to manage class, be more prepared content wise, and enhance communication skills in order to help facilitate students more efficiently.

3. Inquiry-based Science Teaching Methods

Studies suggest that prior to real teaching experience, the pre-service teachers should be exposed to inquiry-based method at college level. It is believed that pre-service teachers who were taught to use inquiry-based method are more likely to develop hands-on activities for their science classroom (Hohloch, Grove & Bretz, 2007); they are also more likely to link science experiments to everyday life. There are five inquiry-based teaching methods, namely simulation, field study, project, demonstration of discrepant events and experiment. All five methods were introduced in SCE550 Science Methods course, with the intention to equip novice teachers with varieties of instructional approaches that they can eventually apply in their science classes.

4. Simulation

Simulation in inquiry-based Science teaching consists of role play, games and model. According to Perry et al. (2009), simulation using model is a form of experiential learning; it is an instructional scenario where the learner is placed in a world made by the teacher. During simulation, the learner will interact in a way where they themselves are the test subject in the lab experiment. This strategy fits well with the principle of constructivism and it also an effective way to help students understand the nuances of a concept or condition. Udo and Etiubon’s (2011) investigation on students’ Chemistry performance shows those who were taught using computer-based science simulations attained better scores than those who were taught using traditional instruction method.
5. Project Work

The project approach in inquiry based science education focuses on the work given by the teacher for the students to carry out in groups. Ideally, there should not be more than three students to a group and the group is required to invent a project for their discovery content purpose (Hiang, 2005). Some examples of projects include developing water filter system from waste materials, to uncover how permanent are permanent markers, and to find out how light effect the rates at which foods spoil, just to name a few. Past studies reveal that project work benefits students in a number of ways: it allows for more meaningful understanding of science concepts amongst students, enhances students academic performance (Ojo & Sola, 2007), and enables learners to engage in the processes of evaluating science content to be learned, anticipating how those knowledge would be used, as well as applying the science content in authentic situations (Kanter, 2008). Project work also helps teachers in the development of their science content knowledge (CK) as well as their science pedagogical content knowledge (PCK) as they prepare and facilitate students’ work (Kanter & Konstanntopoulos, 2009).

6. Demonstration

According to McFarland (2005), demonstration is very helpful in promoting students learning via proving the existence or the truth of something through evidence. Demonstrations of surface tension using varying objects, and of solubility and solutions using salt and canned drink can help capture student’s attention in class. Even though teachers need to put in a lot of work to design, set up and think of the best possible way to carry out demonstration, the end the result can be extremely positive. Not only that, lecture demonstration can become an important component of overall teaching strategy and it will provide a concrete, visual way to help explain a topic. McFarland also found that through demonstration, the nature of classroom interaction tends to be less unidirectional as the students become more actively involved in and start asking questions about the science content. When using demonstration, Miller (1993) noticed that he spends more time looking at students’ expressions compared to the time he spent on writing on chalkboard. By using demonstration as a teaching method, Miller discovered that the method replaces teachers as source of knowledge, and teacher becomes more creative while students learn to respect diversity and work collaboratively.

7. Experiment

Experiment is core of doing investigation in science classroom. Teachers tend carry out experiment as it encourages students’ interest in learning science via provision. Students often find the opportunities to manipulate objects, test hypothesis, and work together to solve or prove something exciting. Also, through experiments, students are usually able to ‘see’ or ‘relate’ concepts better, hence contributing to sound science conceptions. For instance, Olympiou and Zacharia’s (2011) study found that the use of a blended combination of physical manipulative (PM) and virtual manipulative (VM) enhanced students’ conceptual understanding in the domain of light and colour topic more than the use of PM or VM alone. Demeo (2005) also noted that experiments – particularly the transformation of traditional laboratory instruction to one using teaching of manipulative skills - help produce more “mature” type of science education. It is said that the teacher’s actions of redistributing authority between teacher and student when laboratory pedagogy is taking place, as well as the nature of interaction when discussing science issues and findings, do contribute to such outcome.

8. Field Study

Field work is an academic or other investigative studies undertaken in a natural setting, rather than in laboratories, classrooms, or other structured environments (Noel, 2007). Often when a field study is carried out, students learn science content or concepts via observation, (structured or unstructured) discussions as well as through analysis of other forms of collected data. The collected data could be in the form of specimens, video
and/or audio recorded objects and phenomenon. Field study does not only allow students’ active engagement with each other but also helps develop an understanding of the experience and process of learning in natural settings. Preusch (2009) who used field study as an approach to teaching found his students accurately described plants and animals they had observed in different habitats during the field trip. Also, they were able to develop ‘continuity’ between theory and reality via discussions on the lessons learned in classrooms, and relating those with their home life and other experiences in the outdoors. Other advantages of field trip as highlighted by Harder (2010) are students and teachers found the activity enjoyable, learning was more real and more challenging than those done inside the classroom, and learning activities and environment promote aspects of discovery, open discussions, and the freedom to choose how to find and record information deemed most beneficial.

9. Research Methodologies

This study employs a qualitative research design. Three Chemistry Education trainee teachers who were undergoing their teaching practice were approached to request their voluntary involvement as research participants. Apart from occasional classroom observations and semi-structured interviews, other means of data collection is via document analysis. Specifically, two documents were analyzed: reflective journals and record books. While observation and analysis of record book are used to detect the most preferred teaching techniques by trainees (focusing on planned and carried out lessons), data from the record book helps in understanding the development of the inquiry based science education focusing on student’s responses and behavior in the classroom. All research participants were requested to use four inquiry-based teaching methods, namely demonstration, experiment, project work, stimulation and field study. Meanwhile, the interview serves to investigate reasons behind the novice’s teacher pedagogical preferences.

10. Data Analysis

10.1 Record Book, Reflective Journal, Interview

Data in the form of research participants’ documented teaching activities and personal reflections were collected upon the completion of teaching practice session. Specifically, daily lesson planning and reflections of teaching practices were analyzed and scrutinized in depth whilst simultaneously triangulated with the data obtained from the occasional observations, and later with the interview data. The data were coded according to its category and recorded for discussion purposes. The researcher then continues with Cohen Kappa’s peer checker of Agreement as described below:

Step 1: Documents collections (lesson plan, reflective journal and interview) on four teaching methods (stimulation, experiment, project work, demonstration and field study)
Step 2: Analysis of lesson plan, reflective journal content and interview
Step 3: Coding
Step 4: Member’s check
Step 5: Cohen Kappa test of agreement
Step 6: Data recorded
Step 7: Analyze Data
Step 8: Discussion

11. Findings and discussions

The findings and discussion ensue are carefully guided by two research questions formulated at the early stage of the investigation:
1. What are the types of inquiry teaching science preferred by novice Chemistry teacher?
2. How is the development of inquiry teaching applied in their teaching strategies?

**Participant 1**

Participant 1 plans to teach her class on subject acid and base. Based on her lesson plan, it is evident that the participant prefers to use the experiment method:

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Classification between strong or weak acid and strong or weak base.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teacher explains how to conduct the experiment as to differentiate between strong or weak acid and solution.</td>
</tr>
<tr>
<td></td>
<td>The steps are:</td>
</tr>
<tr>
<td></td>
<td>- Dip a pH paper into each of the beaker containing different type of solutions.</td>
</tr>
<tr>
<td></td>
<td>- Wait for a few seconds and take out the pH paper from the beaker and state the pH value by compare it with pH scale.</td>
</tr>
<tr>
<td>Stage 1</td>
<td>Students start to conduct the experiment in group and classify the solution according to their pH value.</td>
</tr>
</tbody>
</table>

**Reflective Journal:** I can see my student’s improvement to be active learners in the classroom and this experiment helps them understand the topic better, the class was in control today.

The findings revealed during the implementation of experiment teaching method, research participant 1 responded positively towards the learning process. By allowing students to engage in hands-on activity via examining changes to the pH paper dipped in different solutions, students began discussing the nature of solutions and how the solutions vary with one another. Through the activity, students become active learners: they started hypothesizing and predicting outcomes, and eventually were able to understand the topic better. These findings are similar to the research carried out by Aksela et al. (2010), Demeo (2005) and Wilfred (2002).

With respect to the development of teaching using experiment, research respondent 1 first explained, in stages, to the class how the trials were to be carried out, after which the students were then allowed to carry out the experiment themselves. Also, whilst showing the experiment, research participant 1 repeatedly highlighted to students the need to observe safety procedures. By first showing how the experiments are carried out, research participant 1 helped her students to (i) take note of different experimental outcomes as well as (ii) ways of organizing the findings of pH papers being immersed in different solutions. In the next class that follows, research participant 1 then somewhat similar approach when using demonstration to teach acid and base concentration.

**Participant 3**

Research participant 3 planned to conduct the lesson on electrolysis by using a simulation. The development of simulation in order are (i) explaining the process of electrolysis, (ii) asking the students to focus on the explanation, and (iii) inviting students to participates in the learning process. The whole process is directed towards encouraging students to personally discover the learning process (Lehesvouri, 2011; Hiang, 2005).

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Electrolysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set Induction</td>
<td>Teacher shows a diagram that consist the two beakers and each containing electrode and electrolyte. The teacher shows- using markers, pencils and perhaps ribbon- the set up of electrolysis, then explain</td>
</tr>
<tr>
<td>Development</td>
<td>Teacher explains first on how the electrolysis process happens, while students focus on teacher explanation.</td>
</tr>
<tr>
<td>Stage 1</td>
<td>Teacher asks students to draw and label diagram of electrolysis.</td>
</tr>
</tbody>
</table>
Reflective Journal: The students were exited to do it as the learning was very interactive; they get to visualize the set-up of electrolysis via using pens, markers and ribbons. Also, the diagram shown was colorful and attractive. Majority of the students understand the topic as they able to answer the excises given successfully.

Based on the activities carried out, students were excited to find out what happens during the electrolysis process. They were seen discussing and trying to predict and explain to one another what transpired at the anode and cathode (Udo & Etuibon, 2011; Schwarz, 2008). On the same topic, participant 3 later conducted experiment in the laboratory and the findings are as below.

<table>
<thead>
<tr>
<th>Lesson</th>
<th>Neutralization Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development</td>
<td></td>
</tr>
<tr>
<td>Stage 1</td>
<td>Teacher demonstrates the electrolysis experiment using copper(II) sulphate, CuSO₄ electrolyte and carbon electrodes, the demo was repeated using cooper electrodes.</td>
</tr>
<tr>
<td>Stage 2</td>
<td>The students start to do the experiment in group while teacher will observe the students’ work</td>
</tr>
</tbody>
</table>

The above findings elaborated on the development on experiment pedagogy practiced by participant 3. The data indicated that student learning began with detailed explanation by participant 3, whereby he outlined clearly the steps involved during electrolysis. During the demonstration session, the trainee teacher were also found to have asked numerous questions, largely focusing on the wrong conceptions students have relating to the topic. Any notions that are deemed unclear or faulty were immediately corrected by the trainee teacher. Upon completing the crucial demonstration and explanation, he then gave the students the opportunity to discover – via conducting experiment - what was shown and discussed earlier. Like research participant 3, research participant 2 also used similar approach when planning and eventually teaching the lesson on electrolysis, suggesting that novice teachers would closely follow the various pedagogies taught to them during the early stages of teaching experience.

12. Summary of findings

The aim of this study to detail out the development of IBSE pedagogies that consist of simulation, demonstration, experiment, project and field study used by trainee teachers undergoing their teaching practice, and to identify the IBSE pedagogies used as well as reasons for choosing the methods. Developmental wise, the trainee teachers followed specific steps when carrying out the IBSE pedagogy of their interest. With experiment, they tend to (i) explain the experimental procedures, (ii) explain safety rules, (iii) answer student’s question relating to ‘what if’ and misconception, (iv) recapitulate the experiment procedure, and (v) give specific directives to get students conduct the experiment in groups. As for simulation and demonstration, all three participants engaged in the following steps: (i) introduce the topic and getting students involved in demonstration, (ii) build the students’ understanding, (iii) ask students to express their misconceptions and questions, and (iv) involve the students in discussion. With respect to the IBSE pedagogies, the research participants generally identified and chose the one that they felt most suited to enhance student’s interest, collaborative skill, whilst simultaneously one that allows students to build conceptual understanding on the topic. All research participants also used experiment so that their students can actively participate in the learning process, make them pay attention in the learning process and enable them to independently carry out further investigations (via asking questions, reading, comparing notes) on the topic. All research participants were satisfied with the choice of their teaching approach; not only did they feel somewhat accomplished in terms of the content they intend teach but also they were happy with the students’ reactions, particularly with the number of hands raised to ask questions, and the nature in which discussion, and information exchange took place.
13. Recommendations

The findings suggest IBSE is a highly recommended approach to teaching. Further investigation on the various IBSE instructional strategies revealed a group of models – the ZYL Triangle models – that would be of great benefit if they were to be implemented in science classrooms. The ZYL triangle model on development of pedagogy consists of three models, each for experiment, demonstration and simulation. All three models were in common in terms of the use of shape, order and reading method. The triangle models can be read through the number sequence exits at the edge of the each triangle. Specific descriptions of the models are as follows:

a. **ZYL Triangle Model on Experiment Pedagogy**

ZYL triangle model on experiment pedagogy can be comprehended through the number sequence that starts, firstly, with teacher explanation on the experiment procedure (by the steps involved), the setting up of apparatus and how the experiment will be conducted. Secondly, the teacher will explain the safety rules, particularly centering on precautionary steps needed to minimize accidents. The third step focuses on answering “what if”, misconception and other questions posed by students. This is followed by recapitulation of steps involved in the experiment, with the intention of making sure students are clear with the overall experiment procedure. The next step moves on into the inside triangle where students start the experiment – be it individually or in group – while the teacher consistently observes the student at work. The final step involves discussion where students state their findings, discuss with other students and conclude the findings whether the hypothesis can be accepted or not.

![ZYL Triangle Model on Experiment Pedagogy](image)

Fig. 1. ZYL Triangle Model on Experiment Pedagogy

b. **ZYL Triangle model on Demonstration Pedagogy Development**

The ZYL triangle model on demonstration pedagogy development can be read using the sequence number indicated on the model, beginning with preparing the materials, contents or aids to be used during the demonstration. This step is followed by the actual demonstration in the classroom. Next, the teacher will stress on the focus point (the ‘what’) that students need to focus on during demonstration. As the demonstration progresses, students will start to develop their knowledge and curiosity regarding the topic. The next step centers on the teacher responding to student’s misconception and questions, followed by actual demonstration by students. At this stage, student representative(s) is called upon demonstrate (usually if it involves experiment). The step that follows involves discussion on the lesson, specifically focusing on the contents of the topic and findings. The last step is recapitulating the lesson whereby the teacher ought to stress on strengthening students’ understanding on the topic.
c. **ZYL Triangle model on Simulation Pedagogy Development**

The ZYL Triangle model on simulation pedagogy development can be read through the number sequences stated at the edge of the triangle.

The first step is teacher preparation of video, model or diagram for the purpose of simulation. Second, the teacher will start the simulation followed by explanation of concept or process. The next step involves students’ development of knowledge and evidence of curiosity based on the conducted simulation. Students are then expected to ask questions and to seek clarifications if misconceptions exist. At this point, the teachers must also pose question to the students as means of assessing students’ understanding based on the simulation. The final step involves going over the lessons whilst elaborating on what students have gained through the simulation activity.

The ZYL Triangle Models are said to be a good guideline for novice science teachers intending to use IBSE. Perhaps future research could further examine if there are different means by which IBSE could be carried out in science classes.

**References**


