Study Note

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Practical Guide of IBSE: A Pedagogical Framework for Primary School Teachers

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Abstract

Inquiry-based science education "IBSE" has been promoted as an inspiring way of learning science by engaging pupils in designing and conducting their scientific investigations. For primary school teachers, the open nature of IBSE poses challenges as they often lack experience in supporting their pupils during the different phases of an open IBSE project, such as formulating a research question and designing and conducting investigations. The current study aims to meet these challenges by presenting a pedagogical framework in which four domains of scientific knowledge are addressed in seven phases of inquiry. My results show that teachers can guide their pupils successfully through the process of open inquiry by explicitly addressing the conceptual, epistemic, social, and/or procedural domain of scientific knowledge in the subsequent phases of inquiry. The paper concludes by suggesting further research to validate our framework and to develop a pedagogy for primary school teachers to guide their pupils through the different phases of open inquiry.

Keywords: Inquiry-Based Science Education, phases of inquiry, the pedagogical framework, lesson plan, domains of scientific knowledge.

1. Introduction

Science education encourages children to develop an understanding of the world around them, and how to think critically about problems and solutions. These are key skills for citizens of the 21st century, who will need to address serious global issues such as climate change and economic crises. Inquiry-Based Science Education "IBSE" is a form of science education "SE" that, unlike the traditional model where the teacher provides facts and the students learn them gives children the opportunity to explore (hands-on), experiment, ask questions, and develop responses based on reasoning (O'Connell, 2014).

IBSE adopts an investigative approach to teaching and learning. Students are provided with opportunities to investigate a problem, search for possible solutions, make observations, ask questions, test out ideas, think creatively and use their intuition. In this sense, IBSE involves students doing science where they have opportunities to explore possible solutions, develop explanations for the phenomena under investigation, elaborate on concepts and processes, and evaluate or assess their understandings in the light of available evidence. This approach to teaching relies on teachers recognizing the importance of presenting problems to students that will challenge their current conceptual understandings so they are forced to reconcile anomalous thinking and construct new understandings (Gillies, 2020, pp 51-55).

Scientific inquiry is regarded as the heart of science education because inquiry helps students develop a deeper understanding of scientific concepts (Aydeniz et al., 2012).

The inquiry may be referred to as a technique that encourages students to discover or construct information independently instead of having teachers directly reveal the information (Smallhorn et al, 2015). However, by the 1950s and '60s, an inquiry-based rationale became more and more visible (Kirchner & Mcmichael, 2015; Linn et al., 2013).

Inquiry-based strategies incorporate questioning and active engagement for student learning. Inquiry uses skills that are active, persistent, and based on a person's knowledge. It involves exploration, questioning, making discoveries, and testing discoveries to search for new understanding (Lemlech, 2009, pp.87-88).

2. The Nature of Science Inquiry

Another foundation of IBSE is an understanding of the process of science inquiry. It is represented here as a framework or set of stages that are quite similar to how scientists go about their work (Figure 1). But there are cautions to observe. The framework is not a set of steps to be followed. Rather it is a series of stages that guide the process. For students, it begins with an exploratory stage where they have the opportunity to become familiar with the phenomenon they will study. It then moves to an investigation stage with many parts. The many arrows in the design and conduct science investigations stage are to suggest that this is not a linear process (Lederman et al., 2013). For example, if the results of students' investigation do not validate their original prediction, they need to question their assumptions, return to the beginning of their investigation and develop a new experiment. If they design an investigation plan and it doesn't work, they need to redesign it (Cairns, 2019). The third stage in this framework occurs when students have done several investigations and are ready to synthesize what they have learned, often as a whole class, and come to some final conclusions. The fourth stage is included here where students communicate their new understanding to a wider audience. There are two final cautions. First, depending on the subjects dealt with, and the nature of the investigation plan. Second, a single session rarely includes all of the stages (National Research Council , 2007).

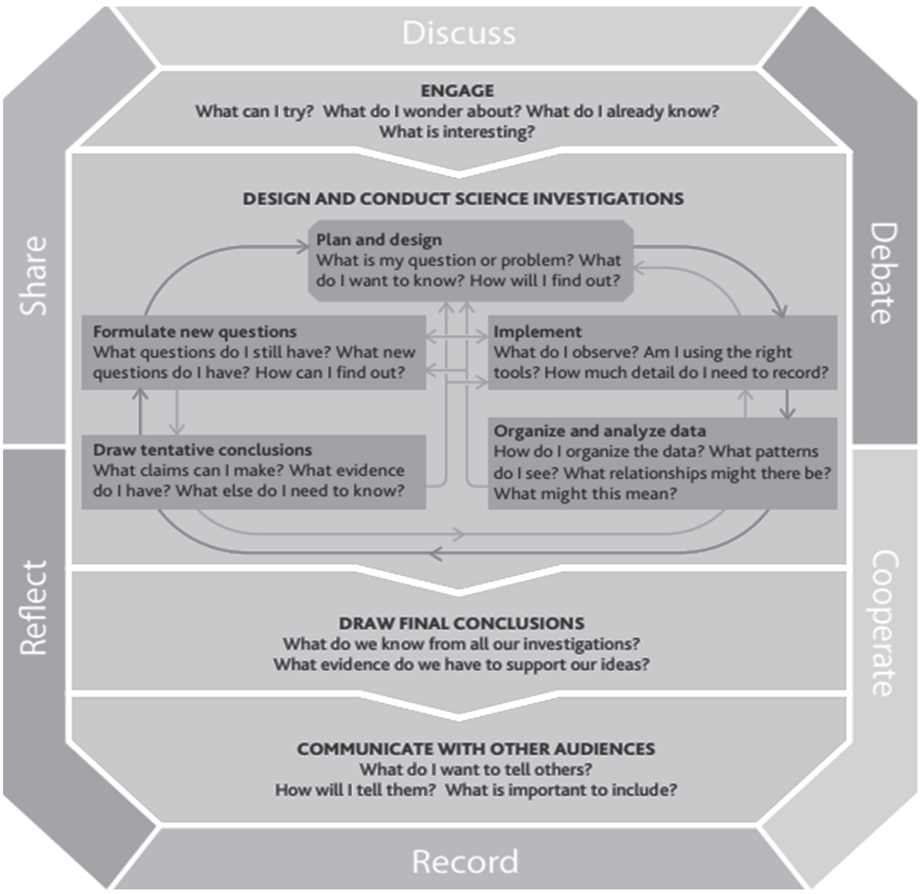

Figure1. Main principles of IBSE (Cicerone et al., 2013).

3. Theoretical Framework

IBSE will look quite different in different classrooms. IBSE will look quite different in different classrooms. There is a great deal of room for individual teachers to adapt and innovate, working from their own knowledge, skills, and interests as well as from those of their students. But there are some important principles that are followed in all inquiry-based programs.

A unit or part of a unit may include several investigations before reaching the draw conclusions stage (Johnson & Johnson, 2002).

4. Important pedagogical considerations in IBSE for teachers

Just as there are important principles to consider when engaging in IBSE.

4.1. Organizing the classroom

4.1.1. The physical environment

If students are to engage in hands-on investigations in teams, the classroom must be set up to make this possible. Teams need space to work together, access to materials, and places to put work in progress. Some schools have a science room where all this is possible (Mieg, 2019). Where this is not the case, it may be necessary to move tables and chairs around, and use small boxes or trays for materials and ongoing work. In primary school, the equipment used for experimentation is generally common and inexpensive ranging from seeds and soil to string and paper clips. Some items are a bit more expensive, relatively few, such as batteries, measuring tools, a scale, and a binocular microscope. In some subjects, such as astronomy or earth science, experimentation with actual objects isn't possible and there may be a need for models, charts, or other media (Gray et al., 2019).

4.1.2. The classroom culture

IBSE is about students working together, trying things out, coming up with and sharing new and tentative ideas, and learning from what doesn't work. This is unlikely to happen in an environment where students worry about having the correct answer. Nor can it happen where the interaction among students is not respectful, certain students always take the lead, or boys are considered the hands-on students (Cicerone et al., 2013). For IBSE to be effective, there needs to be a classroom culture in which all students feel comfortable and all have the opportunity to participate in all aspects of the science work hands-on, thinking, talking, and writing (O'Reilly et al., 2019). If the teacher faces some challenges in this part so we have three practical suggestions for them, first one is if the student is reluctant to share ideas unless they are sure they are right, it can help to talk explicitly with them about the importance of everyone's ideas and the value of discussing something from many points. The second suggestion is questions that you ask can help as well: "what do you think is happing here?" May elicit more ideas than simply "what do you think is happing here?" giving students five minutes to think about the question or having them talk with a partner can also encourage students who are reluctant to speak. The final and third suggestion is establishing well-working teams is not easy. It is a learning process in and of itself. For the student and the teacher. It is advisable to teach explicitly some of the behaviors needed such as how to disagree respectably, listen to each other, share materials, and give everyone time to speak (National Academics of Sciences, Engineering, and Medicine et al., 2021).

4.2. Crafting and asking questions

The questions teachers ask, whether of the full group, small group, or individual, play a very important role in IBSE (Brauma, 1994). Good questions move the work forward; fewer good questions are unlikely to do so. *"A good question is a first step toward an answer; it is a problem to which there is a solution. A good question is a stimulating question, which is an invitation to a closer look, a new experiment, or a fresh exercise… I would like to call such questions 'productive' questions because they stimulate "a productive activity"* (Elstgeest & Harlen, 1990). Productive questions encourage students to start thinking about their questions and how to find answers. Unproductive questions often call for a short verbal response and nothing more. "What is this called? What is a battery? Did the current flow from the positive pole to the negative pole?" This does not mean that the teacher should never ask such questions, but they are not the same as the carefully crafted questions that lead students into inquiry. For this part I have two suggestions for teachers, first, when beginning an inquiry or starting a new investigation, the leading question is very important. It must be specific enough to set students off in the desired direction but it must be open enough that they are challenged by it. For example, the question "what do you think is important to know to light a bulb with a battery?" may be a different form of the question "what makes a bulb light?" Or in other cases what parts does a plant develop as it grows? is less productive than the question "How do you think we might describe the life cycle of a plant?". And suggestion number two is, here are other questions you might ask students as they are working. These two can be more or less productive. For the question, "What differences and similarities do you see between these objects/situations?", "Why do you think these results are different from the other experiment?", "In your opinion, what would happen if...?", etc. (Cicerone et al., 2013).

4.3. Using students' prior experiences and ideas

Students generally have many ideas about the phenomena they encounter in their daily lives. Quite often such ideas are incomplete or contradict the scientific explanations of the phenomena being studied. It is important to keep in mind that some of these ideas, referred to as students' preconceptions, initial conceptions, misconceptions, or naive conceptions may be quite reasonable but are constructed on limited experience and knowledge. One example is the belief that seeds need light to germinate. As plants grow, they do, but initial growth can happen without light. It is important to allow students to share their ideas about the lesson and give them chance to share their knowledge (Muindi & Tsui, 2017).

Teachers who are familiar with the research on some of the more common naive conceptions, who listen to students, and who take their ideas seriously can adapt and guide classroom activities so they provide students with specific challenges that allow new and more coherent explanations to emerge. This can ensure that students have the opportunity to see that other ideas than their own may explain a phenomenon more effectively. (Harlen, 2001). Here we have two examples for better understanding.

Example 1 comes from electricity. Several students believe that putting a light bulb on one battery pole is enough to light it up. There is nothing like letting them experience the phenomenon on their own and see that the bulb will not light. Other students think that electricity comes out of the two poles and enters the bulb. Some will specify that the bulb lights when the electricity from the two poles comes together. Although incorrect, both of these explanations show a certain logic. They know the bulb needs energy from the battery "many have battery-operated toys" and that energy has to get to the bulb but they don't know exactly how. Experience lighting a bulb with wires and using more than one bulb in a series can help them to begin to expand their experiences and arrive at a different conclusion. Example 2 is from a naive conception held by quite a few students relating to their body functions. When asked what becomes of the food we eat, many think there are two pipes, one for liquid and the other for solids. This idea is strengthened by the fact that there are two exits, the anus and another one for urine. In these and other cases, it is important to ensure that the students first express their ideas and, subsequently, are encouraged, through questioning and discussion, to think again. "What happens when you eat minestrone?", "Has something ever gone down the wrong way?", "What does this mean to you?" (Pilcher, 2020). We need to give some suggestions to teachers so the first suggestion is: For students to express their initial ideas, they need to feel that it is OK to be wrong and that their ideas will be respected. In other words, they need to feel that it is safe to share their thinking. Several teaching strategies can be used to encourage this sharing orally and/or in writing. These include accepting students' ideas without judging them even if they are incorrect, and asking students how they know such that "What makes you think that?" "How did you find that out?", and asking for more detail so that they feel that their ideas are valued.

The second suggestion is, if there are students who share ideas that are correct, it is important to simply accept these along with all the others. Any sign that these are correct will likely inhibit other students from continuing to share their ideas.

4.4. Holding group discussions

Discussion amongst students is one of the most important aspects of IBSE. It takes place throughout the inquiry process in pairs, in small groups, and as a whole class. Most students, if they are engaged in interesting small group work, will talk with one another with minimal input from the teacher other than an occasional reminder to stay on track. Effective large group discussions are more difficult and students must learn new skills and habits, as must the teacher create an inclusive discussion environment. Group members will be more likely to contribute to a discussion if they feel they are in a safe, comfortable environment. These are not the more traditional discussions where the teacher asks a question, selects a student to respond, and, depending on the response, validates it or not before moving on to the next question or student (Tayal, 2013). Instead, these discussions are characterized by interaction among students as they add to what someone has said, ask a question, present a different idea, or challenge a peer. The time required to learn the skills required is well worth it (Narendra et al., 2017). When they take place these whole group discussions have an important role to play. They allow the students to make their ideas explicit. Students also hear and discuss the ideas of others, recognizing that the ideas of others may be rooted in facts they had not considered (such as in the spinal cord bone example, mentioned above), and, in certain cases, decide as a group to retest their results and continue their investigations. Eventually, this is the time and place where conclusions are confirmed and agreed upon (Flick & Lederman, 2006). For holding group discussions, we need some suggestions for new teachers to solve this part easily, first suggestion is, it can be hard at first to stop students from talking to you and have them talk with one another instead. Being direct and explicit may help such that "Talk back to Louis, not to me", "Ahmad had a question for you", "Marie, what did you think about what Sam said?", "Allen, do you have anything to add to what Jeanne said?" (Horsburgh, 2019, pp. 67-69).

The second suggestion is, as your role shifts from questioner and teller to facilitator and guide, it is vital that you talk less and refrain from providing or leading students to the correct answers. Likewise, you will want to consider carefully when it is time to intervene to settle a disagreement between two students. Questions and comments such as "How could we find out?", "We may need to try…", and "Let's look at our data...", encourage students to continue the discussion. The third suggestion is to open up discussions to students and presents the issue of what to do with naive conceptions when they are shared. Much depends on when this happens. At the start of the unit or investigation and even as it proceeds, it is usually best to accept a naive idea while at the same time highlighting results that raise questions about it. At the end of the investigation or unit, however, guiding the class to a more accurate conception is important (Brasch, 2020, P.46). The last suggestion is to have more open discussions (Greenspan, 2016, pp. 23-25).

4.5. Guiding student recording

Making a record of science work, including text, drawings, flowcharts, graphs, charts, posters, etc., is an essential part of the IBSE. It supports students learning as they try to clarify their thoughts and put them into words in written form. It helps them realize the progress they have made, remember what has been accomplished, and note the development of their thinking (Stringer, 2002, pp. 55-57).

4.5.1. The science notebook

The primary context for individual student record keeping is the student's science notebook. Just as scientists do, each student in IBSE keeps a notebook.

This notebook may take a variety of forms and include a variety of types of writing (Boxer, 2022, p:34; Mundry et al., 2010).

4.5.2. Team recording

When students take on a group project, the teacher may ask them in advance to prepare a group written record, a poster, an experiment protocol, a technical object, etc., to present their ideas and tentative conclusions to the whole class. These conclusions generated by the working group help them to synthesize their thinking and figure out how to convey to others what they think and/or have done. Such statements may be more formal than the records in the notebooks, as they have to be clear and concise presentations for the other students in the class (Collier, 2015, P. 43).

4.5.3. Class recording

These are conclusions developed jointly as a class with the teacher's guidance, with the specific goal of expressing the thinking of the whole class while ensuring that the conclusions do not stray from facts established by the scientific community. Some would call such writing a summary and/or the "knowledge"

Table 1. Lesson plan for primary school

<table>
<tr><th>Students Activities</th><th>Teacher support</th><th>Time</th></tr>
<tr><td>a) Review the content of learning from the previous lesson.
1. We learn and did the experiments that if the water temperature is 10 °C in 50ml we dissolve 18 g of salt at the maximum.
2. We learn and did the experiments that in 50mil of water we dissolve 4 g of Alum. In total, we dissolve 18 g of salt and 4 g of alum.</td><td>1. In 50 ml of water if the temperature of the water is 10 °C how much salt is dissolved?
2. In 50 ml water if the temperature of the water is 10 °C how much Alum dissolved?</td><td>3 Minutes</td></tr>
<tr><td colspan="2">b) The teacher presents a new inquiry question
If we increase the volume of water, does the amount of dissolvable salt and alum increase?</td><td>2 Minutes</td></tr>
<tr><td>c) Predictions
Students think about the question and talk with each other like:
1. I think both of them can't be dissolved because we have already salt and alum in the water.
2. I think we can dissolve a lot of salt. But before I saw alum is difficult to dissolve because it was hardly soluble in water.
3. I think we can dissolve both because we increase the amount of water.
4. I think alum will be dissolved and salt can't because last time we added a lot of salt in a beaker.</td><td>Teachers give the time for students, first think and then share their ideas with each other's, the teacher should focus on, having the students recall what they have learned so far, and speak about their ideas and the reasons for their ideas. the students listen to their friend's ideas and exchange questions and opinions.</td><td>8 Minutes</td></tr>
<tr><td>d) Experimental method
Students do the experiments after the teacher's directions, for salt: In the beaker, they measure 50 ml of water and the temperature of the water is 10 °C they dissolve 18 gr of salt after that, they try to add 50 ml more water to the beaker and try to how much salt will be dissolved. For Alum: In the beaker, they measure 50 ml of water and the temperature of the water was 10 °C they dissolve 4 gr of Alum now they add 50 ml more water to the beaker and try to how much Alum will be dissolved.</td><td>The teacher is going to introduce the new materials that they didn't use before and after that introduce the method of experiments for salt and Alum. The teacher should focus on, having the students think about the experiment method and what to prepare, and have the students think about what kind of results they expect if their prediction is correct.</td><td>20 Minutes</td></tr>
<tr><td>e) Record the result
In this part of the lesson, the students going to record the result on the worksheet. For salt, if we increase the volume of water "double" then we dissolve more "double" salt in the beaker.
Table A: the record of the result for salt<table><tr><th>Water volume</th><th>Amount of salt that dissolved</th><th>Temperature</th></tr><tr><td>50ml</td><td>18 gr</td><td>10° C</td></tr><tr><td>100ml</td><td>36 gr</td><td>10° C</td></tr></table>For alum, it doesn't dissolve like salt. We increase the amount of water by double we dissolve the double amount.
Table B: the record of the result for alum.<table><tr><th>Water volume</th><th>Amount of alum that dissolved</th><th>Temperature</th></tr><tr><td>50ml</td><td>4 gr</td><td>10° C</td></tr><tr><td>100ml</td><td>8 gr</td><td>10° C</td></tr></table></td><td>Have the students proceed with the experiments as planned, considering safety. Have the students record the results of their experiments and things they noticed in diagrams and sentences, tables and graphs, and other easy-to-see ways.</td><td>5 Minutes</td></tr>
<tr><td>f) Summarizing today's lesson
Students presenting the summary of the lesson:
If we increase the volume of water, so we can dissolve more salt and Alum. Increase the amount of water to double we can dissolve double salt and alum in that water.</td><td>Before summarizing the lesson, the teacher should note important points like, "Have the students think about whether their prediction was correct from the results of the experiments and have summarized what they found in diagrams and sentences" and "Have them compare their results with the results of other groups and present any opinions and questions they have".</td><td>5 Minutes</td></tr>
<tr><td>g) New questions are raised
Students think and ask when I drink tea if it's warm I can dissolve a lot of sugar in the cup, so we want to learn about temperature also. So, the teacher should arrange the materials for the next lesson.</td><td>Have the students talk about their learning for the next lesson. Discuss what will be studying next time</td><td>2 Minutes</td></tr>
</table>

the class has come to. These class recordings are more formal records that express the final conclusions of the knowledge gained during the investigations (Royce et al., 2012).

There are two suggestions for teachers. The first one is that there are many recording skills students need to learn and practice if they are to make the best use of their science notebooks. These may need to be taught specifically (hopefully during their language instruction time). It is helpful as well if students see models of ways to record and have time to share their work. Even very young students can and should record their work in a science notebook. If they do not yet know how to write, you may ask them to draw. Older students are also likely to need guidance on points of detail and labeling as well as on how to use diagrams and other graphics. The second suggestion is, students need to be able to write in their notebooks without being afraid of being judged and corrected by the teacher "spelling mistakes, misinterpretation, incomplete or over-embellished drawings, faulty conclusions, etc.".

5. Inquiry Based science lesson plan

A lesson plan (Table 1) is guided by objectives that the students will assimilate, learn and perform science. It can also serve as "a useful in-lesson reminder to you of your pre-lesson thought" (Milkova, n.d.; Scrivener, 1994).

Topic: Change of dissolvable amount.

The goal of today's lesson: To plan between the amount of water and the amount of dissolvable salt and alum.

Time: 45 minutes

Materials: Alum, salt, water, 2 "200 ml" beakers, a measurable cylinder, bowl, thermometer, ice, stirring rod, dropper, plastic spoon, scale, and a rag.

6. Conclusion

Inquiry-Based Science Education "IBSE" is grounded in the belief that it is important to ensure that students truly understand what they are learning, and not simply memorize content and information. It is an approach to teaching and learning science that comes from: first, an understanding of student learning "students attempt to make sense of the world around them to make it predictable by looking for patterns and relationships in their experiences and through interaction with others and students construct their understanding through reflection on their experiences". Second is the nature of the scientific inquiry.

The process of scientific inquiry can be represented here as a set of 4 stages "Explore, investigate, draw a final conclusion, and communication".

IBSE means students progressively develop their knowledge and understanding of the world around them through their own mental and physical activity. They learn and use skills similar to those employed by scientists, such as raising questions, collecting data, reasoning, reviewing evidence in light of what is already known, drawing conclusions, and discussing results. Genuine inquiry means that students work on questions to which they do not know the answer and which they have identified as their own even if introduced by the teacher.

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