Inquiry Based Learning Pedagogy for Chemistry Practical Experiments Using OLabs

Prema Nedungadi, Prabhakaran Malini, and Raghu Raman

Abstract. Our paper proposes a new pedagogical approach for learning chemistry practical experiments based on three modes of inquiry-based learning namely; structured, guided and open. Online Labs (OLabs) is a web-based learning environment for science practical experiments that include simulations, animations, tutorials and assessments. Inquiry-based learning is a pedagogy that supports student-centered learning and encourages them to think scientifically. It develops evidence based reasoning and creative problem solving skills that result in knowledge creation and higher recall. We discuss the methodology and tools that OLabs provides to enable educators to design three types of inquiry-based learning for Chemistry experiments. The integration of inquiry-based learning into OLabs is aligned with the Indian Central Board of Secondary Education (CBSE) goal of nurturing higher order inquiry skills for student centered and active learning. Inquiry-based OLabs pedagogy also empowers the teachers to provide differentiated instruction to the students while enhancing student interest and motivation.

Keywords: Inquiry-based learning, IBL, Structured inquiry, Guided inquiry, Open inquiry, Virtual Labs, Online Labs, olabs, Simulations, Chemistry, Chemical Sciences.

1 Introduction

Inquiry based learning is an approach to learning wherein the students' quest for knowledge, their thinking, opinions and observations form the core of the learning process. The underpinning postulation for inquiry-based learning is that both

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teachers and students are mutually accountable for learning. Faculties and teachers need to actively participate in the process and foster a culture wherein students are encouraged to express their ideas which are reverently challenged, verified, refined and improvised. This enables the children to deepen their understanding of the concept through interaction and questioning [1]. For students, this teaching methodology comprises open-ended explorations into a concept or a problem. In this process educators play the role of guides helping the students to explore their ideas and take their inquiry forward to make logical conclusions. Thus, it is a co-authored knowledge creation practice wherein educators and students work in tandem to foster enduring learning. This may also foster learning for all in the class and generate significant concepts and viewpoints [2].

Technology has transformed this learning methodology in manifold ways and more and more schools and colleges are resorting to technology centric inquiry-based learning. Educators believe that this learning methodology is highly effective in the fields of science, technology, engineering and math (STEM). These subjects are critical for students to excel in the 21st century [3], [4] and [5]. Research has proven that inquiry and inquiry-based teaching pedagogy is instrumental in developing student inclination towards difficult subjects such as science and maths and to nurture their curiosity and motivate them to learn right from the elementary school level. Comstock et al or Reference [6] analysed the web-based, knowledge-building tool, “Inquiry Page” in the National Science Foundation GK-12 Fellowship Program wherein scientists and educationists collaborate to integrate computer-based modelling, scientific visualization and informatics in the learning of science and mathematics. This allowed teachers and students to collaborate on the inquiry path and establish new knowledge and teaching resources together. A remarkable example of technology based learning for science practical skills is the Online Labs (OLabs). The OLabs Project was introduced to facilitate laboratory-learning experiences for school students throughout India who may not have access to adequate laboratory facilities or equipment [7]. OLabs encourages students to engage in scientific studies and get acquainted with scientific inquiry methodologies through simulations, animations, tutorials and assessment. Another commendable initiative is the Virtual Labs, a multi-institutional OER (Open Educational Resources) which is solely intended to provide lab experiments for undergraduate engineering students. This project developed an extensive OER repository comprising 1650 virtual experiments [8] and [9]. This paper compares three levels of inquiry learning; structured learning, guided learning and open learning and shows how educators may use the Chemistry OLabs to support these three modes of inquiry-based learning.

2 Literature Review

Spronken-Smith and Walker or Reference [10] have advocated inquiry-based learning as a student -centred approach which reinforces the nexus between teaching and research. Inquiry can be understood as the practice wherein students undertake investigative learning about science, conduct experiments, derive inferences from the evidence, evaluate their authenticity and then communicate their findings with due justification [11]. We consider three approaches towards inquiry-based instructions. Firstly, structured inquiry is the methodology in which students work upon an investigative process on a teacher-formulated question within the prescribed framework. The requisite material is also facilitated by the instructor. Teachers are aware of the outcomes but do not disclose them. Students have to discover for themselves through working out relationships between the variables. These are similar to cookbook activities but with fewer instructions and directions. This is the fundamental step suitable for elementary level students. Secondly, the guided inquiry, wherein teachers facilitate the material required for solving the problem at hand and students have to concoct their own procedure for problem resolution. This methodology is suited for secondary school students where framework still needs to be given but there is room for further experimentation. Thirdly, is the open inquiry, similar to guided inquiry but students get the room to formulate their own problem which they intend to investigate. This methodology is parallel to research work in science. Here, the instructor only provides the theoretical framework. Science fair activities are based on open inquiry. This pedagogy is best suited for senior school or college level students [12]. Open inquiry generates greater satisfaction amongst students as they get a sense of accomplishment while conducting the investigation, whereas guided inquiry helps students to produce better documentation for their findings within the provided framework. Thus, open inquiry is suitable for teaching pedagogy where higher autonomy, out-of the-box thinking and in-depth understanding of scientific concepts are warranted [12].

The acceptance of inquiry-based learning is rising and more and more educational institutes at both K-12 and higher education levels are desirous of adopting and integrating the pedagogy with the available technology. However, it is not easy and there are many challenges and barriers in implementing the techniques. The most prominently perceived barriers include the central or state controlled curricula, inadequate time for inquiry, student expectancies and competencies, infrastructure and technology accessibility, resistance from teachers and staff [13] and [14]. Duman and Guvan [15] highlighted the inability of the virtual learning systems to accurately assess the acumen levels of children and help them learn accordingly. This also includes children with special needs. Also, frequently, children are unable to generalize the learning of a session in spite of the session being interesting. However, the biggest challenge is aligning an inquiry-based approach with the mandated time-bound curriculum [16].

3 Inquiry Based OLabs Pedagogy

Inquiry-based strategies in science help students engage in active inquiry, problem solving and decision making and thus discover the significance of science to their lives. There are three different levels based on the manner in which inquiry is facilitated.

1) Structured inquiry: in which the question as well as the procedure for the inquiry are provided by the teacher and the results are to be discovered by the students.

2) Guided inquiry: in which the teacher provides students with only the research question and the materials. Students are encouraged to design an inquiry procedure and then generate the explanation.

3) Open inquiry: in which students generate questions on topics of interest, design investigations to answer the question, conduct the investigations, and communicate their results.

OLabs helps students propose their own research focus, supports in carrying out inquiry-based activities, produce their own data, and continue their inquiry as new questions arise. OLabs helps understanding by facilitating different methods to investigate the same problem.

3.1 Structured, Guided and Open Inquiry Based OLabs

OLabs can be designed to support three modes of inquiry-based learning. Observations and analysis are involved in each mode of inquiry. For each mode of inquiry, there is an instructional plan.

Teachers can design the experiment for structured, guided and open inquiry based on configuring the tabs in OLabs. (Fig.1a, Fig.1b, Fig.1c)

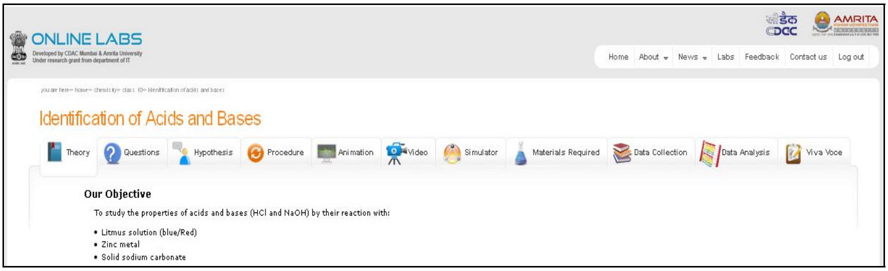

Fig. 1a. OLabs based on structured inquiry-based learning

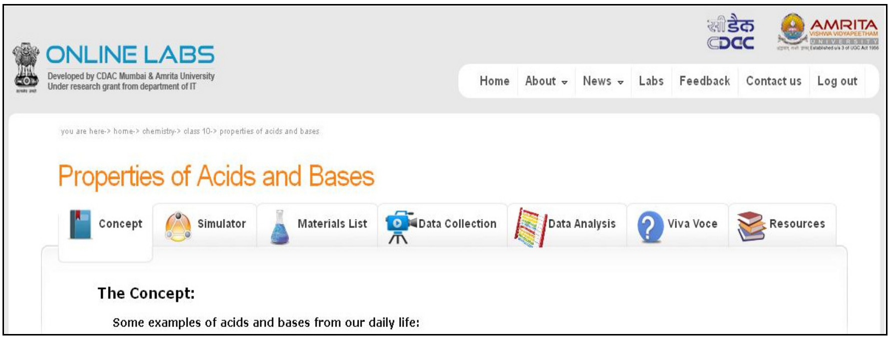

Fig. 1b. OLabs based on guided inquiry-based learning

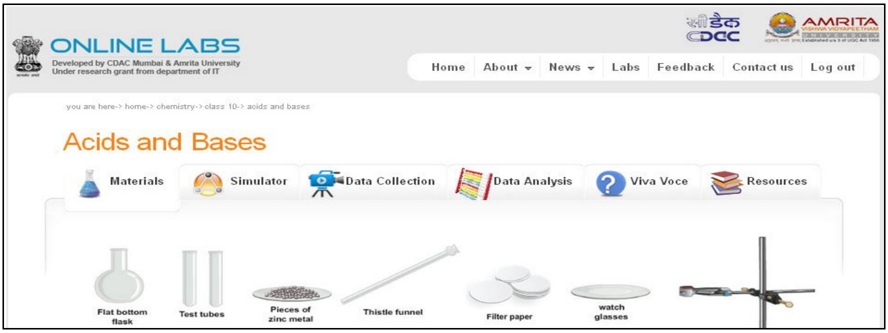

Fig. 1c. OLabs based on open inquiry-based learning

Generally speaking, OLabs may have one or more of the following tabs.

- **Theory** - Consists of the main objectives, concept and learning outcomes of the experiment.
- **Procedure -** Consists of the materials required for the experiment, real lab procedure, simulator procedure and the precautions.
- **Animation** - From the animation, students can clearly understand the methodology to do the experiment in the real chemical laboratory.
- **Simulation** – Using simulations, students can perform the experiments by changing variables and can observe the effect of the changes made. Students have the opportunity to do the experiment repeatedly using simulations until they clearly understand the concepts and the methodology.
- **Video** - Contains video of real laboratory experiments.
- **Viva Voce** - It consists of several questions of multiple choice categories. Students can verify the results of their experiment by answering these questions.
- **References** – Contains references, both book and websites links.

We describe how a Chemistry experiment, "Properties of Acids and Bases" can be configured under OLabs for Structured, Guided and Open Inquiry-based learning methods.

3.2 Selection of Topic

The first step of the OLabs inquiry process is selection of the topic and presentation of the scenario.

In structured inquiry-based learning, the teacher selects and presents the experiment, ‘Identification of acids and Bases’ from OLabs (amrita.olabs.co.in) along with the scenario based on the theory. The teacher can also use the lab videos to explain the methodology and the fundamental principles behind the concept. In the guided inquiry-based learning the teacher presents the scenario to investigate and understand the properties of acids and bases. After presenting this scenario, the students are then encouraged to read the Concept part of OLabs to gain an understanding of acids and bases and their basic properties and to compare them. In open inquiry-based learning, the teacher presents the scenario and asks students to apply it to a real-life problem. An example of an open inquiry scenario would be the following: You are working as a laboratory assistant in a Chemical laboratory. You are provided with colourless solutions in two bottles whose labels are lost. One is used in car batteries and the other is used in soaps, detergents and cleaners. You are asked to give the correct labels to the solutions. Students analyze the problem and decide first to find out the solution used in car batteries and the one used in soaps, detergents and cleaners. Students can conduct research and understand what are the properties of these substances, using any of the OLabs tabs or go to other websites and find out the basic principle of the properties of acids and bases.

3.3 Generating Questions

The next step in the inquiry process is generating the question to start the investigation. A question for our experiment might be, "How will you identify an acid or a base based on their properties?" The student needs to understand the concepts required for this main question.

In structured inquiry, the teacher states the questions for students, based on the objectives of the experiment's theory part. The teacher also explains the theoretical concepts. In guided inquiry, the teacher states the questions for students, such as, "Study What are the properties of acids and bases?". Furthermore, the teacher suggests the concepts that need to be learnt but does not explain the concepts or point to the answers. The students must search the Concept tab or references given in the Resource tab and understand the concepts for themselves. In open inquiry there is no involvement of teacher in the investigation and it is completely student-driven. The student formulates the questions and acquires basic knowledge about the topic. Students can either use the references given in Resource Tab or they can refer to other internet resources. Their findings may take them far beyond the scope of the original problem. The possible questions that students may consider are:

a) Which substance is used in car batteries?
b) Which substance is used in soaps, detergents and cleaners?
c) What are the properties of those substances?

3.4 Background Research

In structured inquiry, the teacher does the background work before designing the investigation. In the guided inquiry mode, students perform the background work before designing the investigation using references in the Resources tab for doing background work. In the open inquiry mode, students perform the background work using any internet resources for doing background work.

3.5 Constructing Hypothesis

In the structured inquiry mode, the teacher discusses the possible hypotheses and the method of investigation. The students write the possible outcomes of the hypothesis and then carry out the investigation as instructed by the teacher. In structured inquiry, the teachers talk about the possible hypothesis to students, based on the theory given in the Theory tab and students examine the hypothesis after carrying out the experimentation. In the guided inquiry, students write about the expected results based on the concept given in the Concept tab before conducting the investigation. Students can verify the hypothesis after conducting the experiment. In the open inquiry, the students write about the expected results before carrying out the experiment. In some cases, the expected results may be wrong. Students can examine the results after the experimentation.

3.6 Designing the Methodology

In structured inquiry mode, the real lab procedure and the procedure for carrying out the simulation are given in the Procedure tab. The teacher can design the investigation for the real laboratory experiment by viewing the animation given in the Animation tab. Students can also understand the real lab procedure from the Animation. Students can further their understanding of the real lab experiment by viewing the lab video given in the Video tab. In the guided learning mode, the teacher provides the list of materials and the students design the methodology for doing the experiment in a chemical laboratory based on the listed materials. The listed materials are given in the Materials list tab. Students also design the procedure for doing the simulation based on the listed materials in the side menu. If students face any difficulty during the design process, the teacher can assist them. In open inquiry, the design methodology is completely student driven. Students first choose the material required for the experiment from the number of materials given in the Materials tab. They have to write the methodology for the real laboratory experiment and the procedure for doing the simulation based on the required materials. In the simulator, a number of materials are given in the side menu.

3.7 Materials and Conducting the Investigation

In structured inquiry, the materials required for the experiment are given in the Materials required part of the Procedure tab. The teacher explains the materials for students based on this Materials required part. All the steps required for the simulation are given by clicking on Simulator Procedure in Procedure tab. Teacher explains the steps to students based on the Simulator Procedure. Students can carry out the experiment using the OLabs simulation. The teacher encourages use of the 'HELP' button to see the instructions. In the guided inquiry, the teacher provides the materials. The students write the entire step by step process for doing

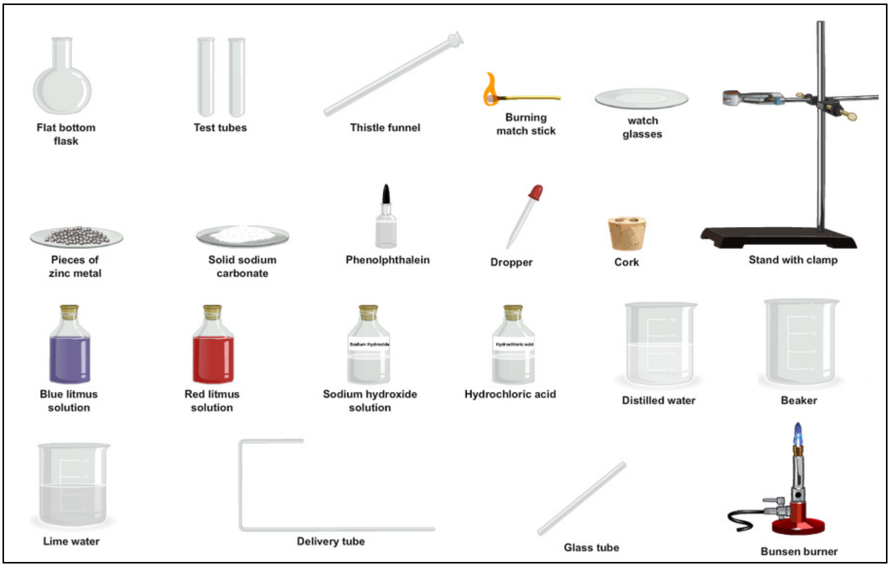

Fig. 2 Materials required for the experiment in structured inquiry

the simulation based on the materials provided and the background research. The listed material for doing real laboratory experiment is given in the Materials list tab. In the open inquiry, the basic methodology of the experiment has to be written by the students, based on the selected material of the experiment. Students can select the materials for doing the experiment from the Materials tab. The methodology should be designed based on the concept behind the experiment. Students can carry out the experiment based on the designed methodology.

3.8 *Collecting and Analyzing Data*

In structured inquiry, teachers guide students to collect and analyse data by giving specific instructions on the methods of tabulation and the type of graph. (Table 1)

Teacher tells the students to verify the results by answering questions in the Viva Voce tab. In guided inquiry, students formulate the observations, tabulation and graph of data. Teacher can guide them if there are any mistakes. In open inquiry, Students have to design the tabulation of the data observed.

Table 1 Tabulation of data in structured inquiry learning

Sample	Colour change on	
	Red litmus solution	Blue litmus solution
Sample 1		
Sample 2		

3.9 Drawing Conclusions

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 own 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. They discuss in their conclusion whether their hypothesis was correct and record the summary of the answers for the questions raised.

4 Conclusions

We discuss the pedagogy of various types of inquiry-based learning such as structured, guided and open inquiry in the context of STEM skills. We present a detailed framework for using OLabs in each of the three inquiry models. We demonstrate the methodology and tools that OLabs provides to enable educators to create the three type of inquiry for science practical skills. The integration of inquiry-based learning methodology and OLabs is aligned to the Central Board of Secondary Education (CBSE) goal of nurturing higher order thinking skills for student-centered active learning. Inquiry-based OLabs empowers the teacher to provide differentiated learning to the students while enhancing student interest and motivation.

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