LEARNING-ENABLED COMPUTER ASSESSMENT OF SCIENCE LABS WITH SCAFFOLDS METHODOLOGY

Prema Nedungadi, Amrita Vishwa Vidyapeetham; Raghu Raman, Amrita Vishwa Vidyapeetham

Abstract

The crucial role of hands-on science experiments in the school science curriculum is universally accepted. However, a formal assessment of practical skills is lacking, with most schools employing traditional theory-based or multiple-choice questions (MCQs) to evaluate students. In this paper, the authors present a framework for learning-enabled assessment of practical skills, which gives due consideration to both the structure of the practical assignments and the feedback that promotes learning. This approach opens up many new possibilities that require constructivist learning and higher-order thinking skills. Judgment of skills based on performance reports may decrease students' confidence, whereas scaffolds used during the assessment process can improve students' proficiency. The design of various online scaffolds—used during assessment that help students focus and redirect their efforts to the appropriate task needed for mastery of a skill—are discussed here. Early studies have shown that students prefer these types of assessment to more traditional ones, where intervention includes appropriate hands-on simulation or interactive animation or a given concept.

Introduction

The National Focus Group on "Teaching of Science" suggested prevention of marginalization of experiments in the school science curriculum. In this regard, investment is required for improving school labs to promote an experimental culture. However, there seems to be two main difficulties.

1. Experiments require a certain minimum infrastructure; a lab with basic equipment and materials. Azad et al. [1] have shown that learners have access to the physical lab for only a short period of time; thus, the learning cycle is limited as the time is often insufficient for trying different scenarios.
2. Assessment of practical skills in science in an objective manner is a difficult task. The difficulty increases manifold if the assessment is to be carried out with a large. This lack of infrastructure and, more importantly, lack of reliable assessment has resulted in the unfortunate neglect of experimental work in many schools.

The Central Board of Secondary Education (CBSE) in India has mandated continuous assessments in both theory and practical skills. As per the current assessment scheme, theory and practical examinations have a weight of 60% and 40%, respectively. The practical examination is comprised of two components.

1. A multiple-choice format, which raises a question of how to test accurately when the majority of the questions are multiple choice, where intelligent or random guessing is common? It should be noted that there are no negative marks for incorrect answers.
2. The other component is the actual performance of the experiment by the student in the lab.

Currently, CBSE has made sure that expensive equipment is not part of the practical curriculum so that most schools can afford it. Online labs can remove this limitation and allow students to practice in all areas of experimentation, irrespective of the expenses or cost involved. Integrating online labs with assessment of practical skills can offer support for the Continuous and Comprehensive Evaluations (CCE) program mandated by CBSE.

Scaffolds Used During Assessment

One of the most important components in course evaluation is the assessment of lab work. Today, lab work is often judged by the results (summative assessment) observed in the written lab reports (reporting-related skills) submitted by students after experimentation, rather than evaluating the skills acquired by students and providing immediate feedback (formative assessment) while conducting the experiment in the lab (procedure-related skills). Practical skills assessment needs to evaluate both reporting and procedure skills. Weights for procedure and reporting skills in each experiment need to be determined based on the lab objectives set for that particular experiment. An often neglected but important component in making learning effective is the assessment of learning, as traditional assessments of labs are often limited to theory and multiple-choice questions.

The objective of this study was to design and develop a system for Computer Assessment of Practical skills (CAPS) capable of assessing an experiment's procedural, manipulative and reporting skills. Having these experiments available online addresses the issues of simultaneous access for large numbers of students and being able to evaluate them.

Literature Review

Bryce and Robertson [2] in their review of the literature regarding assessment in the lab wrote that in many countries teachers spent a considerable amount of time in supervising lab work, but the bulk of science assessment is traditionally non-practical in nature. Based on a study in the context of learning in Biology conducted by Yung [3] in Hong Kong, he presented data that demonstrate the complexity of assessment in school science labs. He claims that even as we enter the 21st century, teachers continue to assess their students using paper and pencil tests, thus neglecting many of the most important components of students' performance in the science lab in general, and the inquiry laboratories in particular.

Continuous assessment of practical work is necessary to adequately cover the variety of tasks and skills that comprise a total program of science-based practical work. The advantage of the continuous assessment of students' work in the lab is discussed in detail in a comparative study by Ganiel & Hofstein [4]. Computer Assisted Assessment (CAA) can stimulate, motivate, be diagnostic and reinforce learning by providing directed feedback [5].

Gibbs et al. [6] addressed the purpose of lab work as follows:

- Developing practical skills
- Familiarization with lab equipment, techniques and materials
- Developing data-recording and analysis skills
- Developing experimental design and problem-solving skills
- Developing communication and interpersonal skills
- Developing technical judgment and professional practice
- Integrating theory and practice
- Motivating students

Even in schools with labs, considering the varied ability level of students, the allocated time for experiments is often not enough for all students to complete their tasks satisfactorily and gain sufficient experience through the process [7]. Scaffolding is the precise method that enables a learner to achieve a specific goal that would not be possible without some kind of support [8]. Puntambekar & Hubscher [9] described the central features of scaffolding as: common goals, ongoing diagnosis, dynamic and adaptive support, dialogues and interactions, and fading for transfer of responsibility. Scaffolding can also be characterized as helping the learner with the more difficult or extraneous portion of the task, thereby allowing the learner to complete the primary learning objectives, the real task, of the activity [10]. Scaffolding is also linked with formative assessment through the shared characteristics: eliciting prior knowledge, providing feedback, teaching for transfer, and teaching students to self -assess [10].

Human tutor scaffolding may be more valuable than computerized or written scaffolding because of a human tutor's ability to pick up on subtle cues from the student [11]. However, several authors acknowledge that one-on-one scaffolding cannot readily occur in a classroom with many students and one instructor.

Amrita Learning

As part of the Amrita Learning Initiative, an Adaptive Learning Management System (ALMS) was created. ALMS emulates a one-on-one tutoring system based on intelligent learning principles. Various modalities support the different visual, auditory and kinesthetic learning styles, and learning preferences support tutorials, animations, videos, graphics, simulations and summary or detailed information [12]. The initial application of ALMS was in the development of adaptive assessments with automatic presentation of multimedia tutorials for intervention based on proficiency levels [13].

Amrita Learning Online Labs

Amrita Learning Online Labs (ALOL) is based on the idea that lab experiments can be taught using the Internet, more efficiently and less expensively, and offered to students who do not have access to physical labs. It was developed to supplement the traditional physical labs. It may even replace the traditional labs as is the case with rural schools in India, where lab facilities are missing, enabling them to compete with students in better schools, thus bridging the digital divide [14]. ALOL further helps students prepare themselves before attending a lab by becoming acquainted with the equipment, going through pre-lab exercises and taking pre-lab quizzes, both on the content of the work and on the safety considerations of the lab, all through online exercises.

Raman & Nedungadi [14] have detailed the steps to provide students access to online science labs and to perform, record and learn experiments anywhere, anytime. There are ranges of learning models in which these resources can be used and the benefits of using these as learning aids have been widely accepted. Online labs may be offered as a pre-lab learning tool to provide additional activities, to support teaching or learning of a concept and to evaluate the student. It can also be used as supplementary learning in schools which have the physical equipment to perform the experiments, but have no physical labs.

Computer Assessment of Practical Skills (CAPS)

Assessment can be enhanced using multimedia to assess higher-order thinking skills and problem solving, and can enrich the experience. In the Amrita system, students can explore, construct and experiment before coming to a solution.

CAPS tests the following skill areas:

- Procedural and manipulative skills
- Concepts and understanding skills
- Reporting and interpretive skills

Implicit feedback occurs with ALOL in that the learners see the results of their action. However, in order to provide formative assessment to assist learning, further feedback is required.

With CAPS, students will be able to

- perform the actual experiments on the computer and record answers (steps followed in performing the experiment will also be recorded and observed);
- manipulate, observe and interpret or predict during assessment even with multiple-choice questions; and,
- get immediate feedback on their actions.

Assessment of Procedural and Manipulative Skills

Under this category, a student must be able to select the appropriate apparatus (Figure 1) or sequence the steps (Figure 2) needed to perform the experiment and remove unrelated ones. The student should know the limitations of the apparatus and be able to assemble and handle the instrument. The student should be able to rectify errors in an apparatus and dismantle the experimental setup.

The student may be asked to choose either the correct apparatus or the materials needed for an experiment, or assemble the materials for a given set. For example, a commonly used experiment for Newton's Second Law of motion is the cart experiment, where the cart accelerates when an external force is applied to it. The aim of this experiment is explore the relationship between the magnitudes of the external force and the resulting acceleration.

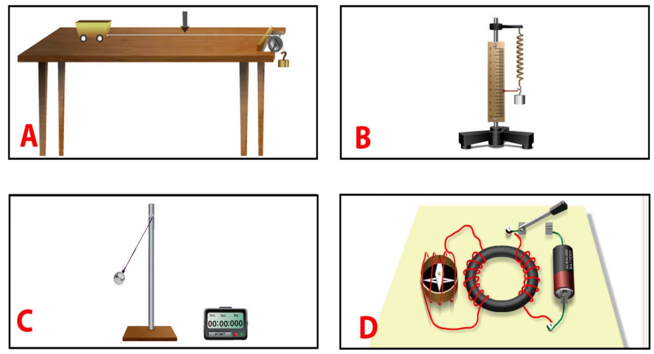

Figure 1. Assessment Asking the Student to Select the Right Apparatus

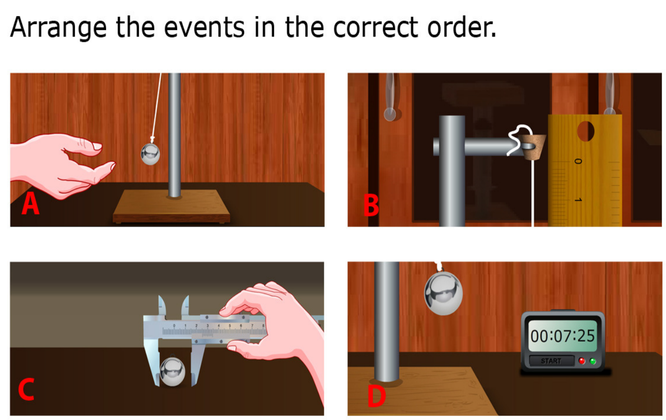

Figure 2. Assessment Asking the Student to Sequence the Steps for the Experiment

The variables for this experiment include changing the friction, the weight of the cart, the weight to be hung, and the distance moved by the cart. In another instance of this simulation, time is a variable while the distance is fixed.

Assessment of Concepts and Understanding the Experiments

This includes reading the instruments correctly, noticing the color changes or any visible changes, locating the desired parts in a specimen, and understanding the scientific concepts and applications of the experiments. The sample question of Figure 3 shows the scaffolds used for an experiment.

Choice a) is the incorrect observation and, hence, the correct answer choice. In case a student incorrectly selects choice b) instead of a), the first interactive animation (Figure 4) shown would be to teach the learner that b) is actually a valid choice; the second animation (Figure 5) would show that a) is an incorrect choice. The student can perform both simulations to understand the concepts.

In an experiment to test the pH of a given sample using pH paper, four students recorded the following observations:

Sample Taken	pH paper colour turned
a. Water	Blue
b. Dilute HCl	Red
c. Dilute NaoH	Blue
d. Dilute Ethanoic Acid	Orange

Which one of the above observations is incorrect?

Figure 3. Multiple-Choice Question Testing Understanding of Concepts

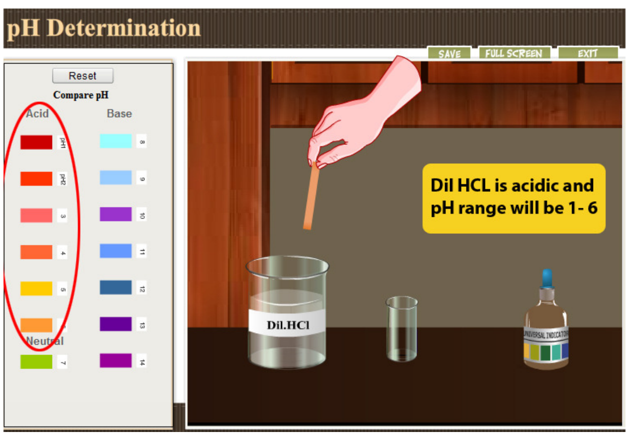

Figure 4. First Scaffold to Learn From the Error

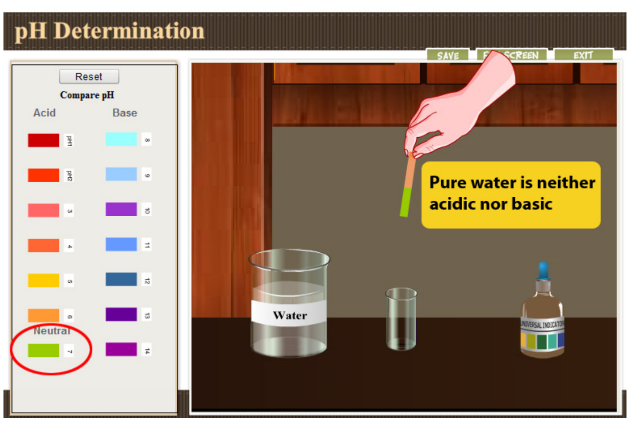

Figure 5. Second Scaffold to Help Learn From the Same Error and Show the Right Answer

The simulation of Figure 4 shows that dilute HCL is acidic based on the color change. Its pH value can be obtained by comparing the color of the pH paper to the colored boxes with the PH value shown against each box. The simulation of Figure 5 shows that water is neutral based on the color change of the pH paper and thus is non acidic.

Assessment of Reporting and Interpreting Skills

These include recording the observations, data and information correctly and systematically; classifying and categorizing the data; making correct calculations with observed data and using the right formulas; reporting results using correct units and symbols; and, interpreting the results correctly.

- Record the observations, data information (Figure 6)
- Choose the appropriate graph and label them
- Plot the data points on a graph (Figure 7)

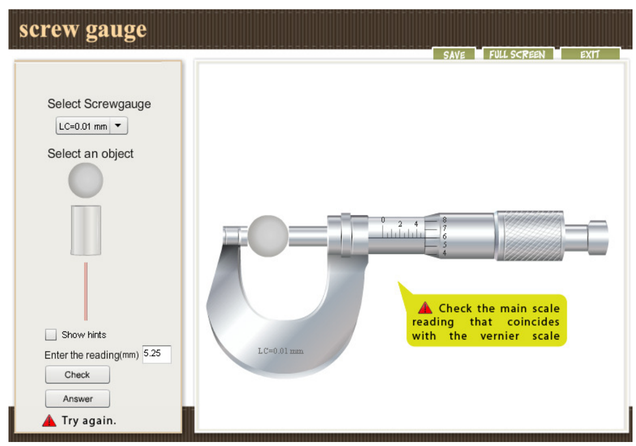

Figure 6. Assessment with Feedback to Compare Student Reading of Data to Stored Experimental Data

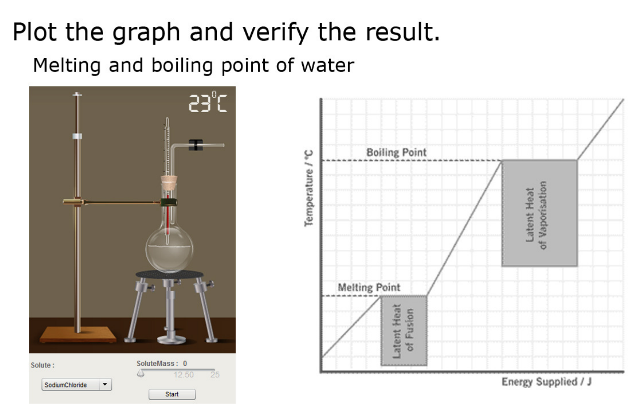

Figure 7. Assessment to Plot a Graph Based on the Simulation

Take the case of assessing a student's ability to record observations. A simulation is shown with a fixed starting set of variables and viewed up to the end. This part is a passive viewing by the student and can be replayed as necessary. Then, the student may be asked to choose the correct table format and enter the variables and the recording observed. Sample questions can include recording information about the experiment, observing results and creating a graph for the readings.

Assessment Scheme for a Sample Experiment Based on Skill Areas

Table 1. Weights for the Different Skill Areas

Skill Area	Weight
Procedural and Manipulative Skills	35%
Concepts and Understanding	40%
Reporting and Interpretative Skills	25%
Total	100%

The weighting for the different skill areas can be varied based on the nature of the experiment and, as such, the assessment scheme must be transparent to the students.

Recording and Reporting of Experimental Data

Every input from the students is tracked, including the current state of the experiment, mouse clicks, variable changes, pages visited and time spent. This provides a complete history of all student activity. Based on the analysis of this data, the learning style and the student level, scaffolding intervention—in the form of thinking clues, tutorials, reviews or help—is provided, much as the teacher would do in such a situation. Such data can provide insights for both teachers and students into strategies, common mistakes and missing concepts after exercises. It is also possible to distinguish between a problem-solving attempt involving guess work.

This project was implemented for a period of 13 weeks with 36 students and 3 teachers. A total of 3 sets of experiments were considered. On average, each student spent 2 sessions of 25 minutes each per week working on the system. Table 2 summarizes the results of a questionnaire given to the students. A 5-point Likert scale was used to administer the survey.

1 = Strongly Disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly Agree

Table 2: Results of Questionnaire Proposed to the Students

Questions	Average
Simulations were helpful to understand the con-	4.9
I like the way system provides hints during ex-	4.7
I like the way I can manipulate the equipments	3.8
The system is easy to use	4.7
I like the fact that I can see the results of my	4.9
I like getting immediate feedback on my work	4.8
I do not see too much advantage of CAPS over	2.6
The actual process of using CAPS is enjoyable	4.8
The project should be extended to all Science	4.7
It has helped me understand concepts in the	3.5

Given the high costs of building a physical lab and the amount of time it occupies in the school curriculum, effective assessment of practical skills is important. Though there are many online labs, such learning-enabled assessments for online experiments with scaffolds are still not commonly available.

The main considerations of a new technique for assessing online labs discussed here are:

- Design and architecture of online labs with scaffolds built into assessment for online labs for procedure, manipulative and report-related skills.
- Additional costs and time involved to build such scaffolds for the online assessment, taking into account the time spent in creating animations, taking videos, drawing graphics, making simulations, preparing tutorials, procedure or detailed information and developing the appropriate software.
- Early studies have indicated that the majority of the students are interested in learning-enabled online assessments.

Current work includes large-scale qualitative and quantitative studies to analyze and measure differences in learning concepts using traditional and scaffold methodologies, adapting online labs and scaffolds that are specific to mobile/tablets.

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Biography

PREMA NEDUNGADI is a PI for the Online Labs for Schools from Department of IT and a joint Director for the Center for Research in Advanced Technologies for Education (CREATE) at Amrita Vishwa Vidyapeetham where her research projects include areas of Adaptive Assessment and Learning, Virtual Simulation Labs, Language Labs and Collaborative Authoring and Learning Platforms. Her prior background includes 15 years of Software Architecture and Management at Sybase Inc. and Redbrick Systems (IBM), California. Dr. Nedungadi can be reached at prema@amrita.edu

RAGHU RAMAN is the Principal Investigator from Amrita for the National Mission on Education through ICT (MHRD) project on ERP and the Principal Investigator for Online Labs for Schools from Department of IT, Government of India and for the Measuring Learning Consortium, under the HP Catalyst Initiative . He heads the Center for Research in Advanced Technologies for Education, CREATE @ Amrita, guiding research projects in the areas of Adaptive Learning Systems, ERP Systems, Virtual Labs with scaffolds, Intelligent Video surveillance, Multimedia technologies in education that has societal impact. Raghu has over 22 years of executive management experience from NEC Research Labs, IBM, and Informix etc. Dr. Raman can be reached at raghu@amrita.edu