Current Status of Assessment of Experimental Skills in Science Education: A Perspective from India

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Abstract
Experimental skills are very important for science students, and it is necessary to visualize them by evaluating student achievement. It is appropriate to acquire experimental skills by carrying out science experiments in labs. Testing the students' experimental skills involves assessing their capacity to use their knowledge in practical ways. Although it is obvious that practical abilities in science are important, it is unclear exactly what these skills are and how they might be most efficiently and accuraters be assisted in understanding the function of practical work and necessary to embrace more recent ally evaluated. Engaging student in high-quality practical work at a younger age can aid in the development of important skills, a thorough knowledge of scientific inquiry, and conceptual comprehension. It is crucial that teacheternative teaching and evaluation techniques. This article reviews how experimental skills are currently assessed and the importance of evaluating these skills in science.
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1. Introduction

Every time anyone recalls a science class from their school or college days, it is the laboratory work or the time spent in the laboratory that is still fresh in their memory. This has always been the most distinctive feature in science learning. Although the majority of science teaching community concur with the important role played by the laboratory/field work, the exact role and function of the laboratory science learning is still debatable. The age at which formal science learning begins in the education journey of a learner (most often between the age of 10-12years), the learner/student is still in the concrete operational stage of cognitive development. This means the students will learn scientific concepts better when they observe or touch and feel through experiments, which is exactly the role played by laboratory work in learning science. Therefore, laboratory (or practical) work can be described as the process of learning science through observations and experiments either in a laboratory or a field. During higher education, the learners get to observe, manipulate and document data to finally understand a scientific concept or principle. Further to this, the skills developed in the process of experimentation allow students to apply this knowledge in practical situations and also enhance their capabilities to learn **[1, 2, 3, 4]**. Hence laboratory has been at the core of science learning, over the past years during the reformation of science curriculum **[5]**.

Numerous research studies have looked at whether and when students develop the necessary experimenting abilities, which are a crucial part of scientific thinking. It is important that students practice experimental skills, and for this visualization of experimental skills and evaluation of achievement are necessary. By indicating the achievement levels, a better understanding of the measurements and see how students' skills are developing. So, to acquire a more accurate description of experimentation, this article reviews how experimental skills are currently assessed, in India and globally, and its importance in science education. Finally, some suggestions on assessment of science practical work in a better way in light of various sources of evidence have been provided. The phrase "experimental skills," which is discussed more below, is used in this article to refer to those abilities that improve a student's capacity to engage in any type of science learning activity that entails handling and/or viewing actual items and materials.

The term 'experimental skills' has been used to describe the different aspects of the practical/experimental/activity-based approach to teaching and learning science. Firstly, experimental skills could be acquired by students simply observing and manipulating scientific instruments or real objects in a laboratory or an outdoor setting. This could enable teachers or facilitators to generate a certain level of curiosity or interest in the students towards science learning. Secondly, experimental skills could enable students to grasp scientific concepts better and motivate students to recognise the value of evidence-based learning in science and scientific research. Experimentation by a scientist to solve complex science problems involves performing certain critical laboratory or outdoor experiments. However, the basic foundation for the skills required to perform such experimental work needs to be built at the school level science learning. The pertinent implementation of experimental work will result in building a scientific attitude in students which would motivate them to pursue science in higher classes. But the learning outcomes of implementing experimental work can be measured only through proper assessment.

A study by *Eva Trnova et al* in 2006 has classified the experimental skills into various levels. It includes 1) Experiment designing and planning, 2) Experimental apparatus designing, 3) Experimental apparatus formation and examination, 4) Development of an experimental procedure, 5) Data collection and presentation in appropriate format and 6) Analysis of experimental results **[6]**. These encompass the steps involved in the process of performing experimental work for a particular research question. Ultimately, the objective behind the experimental work should be to help students to identify the connection between the observation made during experimentation and its application in the real world. Therefore, the perfect amalgamation of experimental work and theoretical knowledge/instructions result in better application of scientific knowledge. In order to achieve the above said objective of experimental work, it is important to implement it appropriately and assess the outcomes. Certain factors like age (or the grade), cognitive abilities of students, and the aim of the practical work needs to be considered carefully while designing and implementing experimental work. As the achievement levels of the students are assessed, it will be possible to further improve the students' skills.

The majority of educators concur that engaging students in high-quality experimental work can aid in the development of important skills, a grasp of the methodology of scientific inquiry, and conceptual understanding. Learning about risk, hazard, and safe working practices is another benefit of engaging in practical science work. Before deciding to do any experimental activity, it's a good idea to ask, "What will the student learn from this experiment that they won't learn at all, or won't learn very well, when they are just told what happens?" This question will assist in defining the activity's goals and defending its use. Students can create a bridge between what they can physically see and touch (hands-on) and scientific theories that explain their observations through really effective experimental activities (brains-on). Since making such linkages can be difficult, successful practical tasks are more useful in doing so **[7].**

2. Stages of science experimental skills

To inculcate the science experimental skills, it will be essential to follow a process keeping in mind the grade or age of the students. Depending on the cognitive abilities of the students, the experimental skills should be implemented in different phases which can be described as follows **[8]**:

1. ***Motivation stage:*** Motivation is the key to engagement. Any science learning exercise without engagement is futile. Therefore, it is important to keep the students motivated to study science experimentation. **Libao et al.** showed that extrinsic motivation towards science learning had a profound effect on the academic outcome of learners **[8]**.
2. ***Stage of subject orientation for acquiring the process skills****:* Gaining knowledge required for the experimental skill is the first stage of subject orientation. This knowledge will help the students to think and ideate the experiments, which is an important step towards acquiring experimental skills. In this process, the learner also acquires new experimental habits which help the development of sensory and motor skills required for experimentation.
3. ***Stage of "crystallization" of acquired skill****:* At this stage, the learner becomes confident of the skills acquired during orientation and will be able to complete simple practical tasks or simple experiments.
4. ***Stage of inclusion of the process skills into a wider contextual frame:*** Further to the crystallization stage, the learner will start applying the skills to solve extended problems that are more challenging and requires application of the acquired skills of experimentation.
5. ***Stage of integration:*** The learners' talents are incorporated into a skill structure in this stage: tackling difficult work, difficulty situations, and research experiment projects.

3. Current assessment of science experimental skills in India

The information regarding the current methods of evaluation of experimental skills, emphasizing the Indian scenario, has been carried out through straightforward documentary analysis of the published literature and personal communications. The discussion is further extrapolated to the importance of evaluating experimental skills in science.

In India, the methods of assessment differ with a change in the degree awarding body and level of qualification. Conventional subjective pattern of assessment has been in place for a very long time. With no stipulated guidelines, the current assessment experimental skills are reliant on the expertise and experience of the examiners. The major drawback of this practice is the inappropriate assessment of students' objective characteristics or abilities like cognitive, psychomotor, affective, behavioural, etc. On the other hand, it may give one or more abilities disproportionate weightage as well. Since every student is different, this method of assessment might be extremely unfair for the learners and the uniformity of evaluation cannot be achieved **[9].** The current assessment method does not consider the ability of the student to complete the task and the process of examination is not as important as the final result of the experiment. The emphasis is more on overall performance more than the presentation of specific competencies. Students don't receive adequate feedback regarding their performance. Therefore, the educational objectives are not met and the aim of assessment is not served due to lack of objectivity **[10, 11].**

In support of the crucial role played by proper methodology for the evaluation of experimental skills or practical examinations in general, there have been several surveys on the current method of evaluations at graduate level. A study by Bharat Gajjar assesses the mode of evaluation of the pharmacology practical test for undergraduate medical students in Gujarat State were assessed. The pharmacology practical test is administered using a variety of tasks to gauge diverse competencies. The exercises and their weighting vary widely, despite the fact that the exam's format satisfies the goals laid out in the Medical Council of India (now called National Medical Commission) standards **[12, 13]**. In another study, the need for changing the biochemistry practical curriculum in one Indian state—Maharashtra—is evaluated. The study found that the practical biochemistry curriculum needs to be reorganised, and a new curriculum that has a greater focus on clinical applications should be introduced. To improve the attitude of Indian medical students toward contemporary trends in biochemistry, obsolete curriculum should be replaced with creative curriculum with a more conceptual and global perspective **[14]**.

There were attempts to add some objectivity to the examination in light of these restrictions. One such attempt was the introduction of objective structured practical examinations (OSPE)/Objective Structured Clinical Examinations (OSCE), mostly used in Medical/Dental colleges. The OSPE is far superior to the traditional style of examination in many aspects. By breaking an experiment into several steps and assigning weightage to each aspect of experimentation, it seeks to cover all potential areas of student assessment **[15].** However, this form of evaluation requires a high number of examiners, poses some logistics issues and time restraints, making OSPE implementation challenging **[16, 17].**

Reem Rachel et al has undertaken the study to determine the reliability and student satisfaction with OSPE as a method of assessment of laboratory exercises in physiology at Melaka Manipal Medical College, India. The feedback indicated that students were in favour of the OSPE compared with the traditional practical examination **[16]**. Another study by Mamtha SD et al explored the perceptions of faculty on OSCE/OSPE in physiology examinations. According to the findings, more than 60% of professors said that the OSPE was cognitively and physically demanding and that more professors were needed to administer the tests **[17]**. While such studies found that both the students and faculty were satisfied with the OSCE/OSPE for practical examinations during a Medical course, these examinations come with their own set of challenges. A considerable limitation identified by Bhatnagar KR et al is that the organizers of these examinations are required to spend a significant amount of time and energy in planning and preparation for the test. It is also important to sustain the motivation among the faculty, especially in the transition from traditional method of examinations to the more rational, objective, and methodical OSCE/OSPE **[18]**.

Until now, we have discussed the status of assessment of experimental skills during graduation and above. However, as per our literature survey, there are no reports in India, explaining the scenario in schools. There are many challenges in initiating practicals at school level in developing countries like India. First of all, the exposure to practical skills is very limited in the school science curriculum in India. Furthermore, the logistics issue of having all the facilities for experimental work in a school set up is challenging. The next challenge is to find teachers equipped with the necessary practical knowledge/skills and also a grasp of the process of evaluation of the students' practical skills. With all these milestones in the pipeline, the National Education Policy (NEP) 2020 is set to change the Indian Education System and also gives the well-deserved attention/importance to the practical skills of students and empowering the teachers to achieve the same.

4. Need for a rubric

Whether or not a student has attained a particular skill can be understood only by proper assessments. It is very important for a proper method of evaluation/assessment in order to ratify the attainment of experimental skills. In the previous section, we discussed the usage of OSCE/OSPE in the Medical education in India and other countries. Similarly, in any other education sector, development of a specific rubric has been extensively tested and recommended by many researchers. Whilst using a rubric enables students to demonstrate not only their understanding of how practical work should be undertaken in terms of the design, collection of results and evaluation of the experiment but also their competency in actually using their experimental skills.

During the learning of science, it is very important to offer multiple learning opportunities to students. Laboratory investigation is one such major opportunity where the students get to observe certain scientific phenomena, design and perform scientific experiments/activities, and interpret the results. This develops scientific inquiry and problem-solving capabilities in the students. However, without proper assessment, it is not possible to verify the skill attainment. Depending on the goals of the laboratory experiments, rubrics can be developed for assessment. Rubrics can be described as an assessment tool or a scoring guide that considers all the achievement criterion expected from an assignment for assessment. It is always suggested to validate a rubric and then implement on the test subjects/samples. A lot of studies explore the use of rubrics in assessment of practical skills. Certain studies have come up with a rubric specific to a subject like physics, chemistry or biology **[19, 20, 21, 22]**. Considering the overall achievement in science laboratory sessions, certain other researchers have developed rubrics for assessments **[13, 24]**.

5. International analysis of current assessment of practical skills in science

Different methods have been employed over time to evaluate scientific practical work for summative purposes **[25].** The same evaluation system is often utilised for different branches of science, while evaluation of fieldwork, when it occurs, is typically limited to biology and/or earth science. The system in place in England today has a few unique characteristics, one of which is the scant amount of direct evaluation of students' practical abilities. As **Donnelly et al.** has observed, because there is little direct evaluation of practical abilities, teachers do not invest too much of their time and energy in lending a hand to students to develop their practical skills as they teach for the exam **[26]**. As opposed to summative assessment, which involves giving students a final evaluation, mostly at the end of the semester or academic year, formative assessment involves the teachers giving students feedback for the betterment of their learning all through the course of the semester or year.

The curriculum, and especially the associated summative assessment, has a considerable impact on the practical work that teachers choose to conduct with their students, according to recent studies in both the domain of practical work and the assessment of scientific education more generally **[27, 28, 29].** Surprisingly little appears to have been written in the academic literature about what constitutes "good" summative assessment of experimental work since the study by Gott et al., **[30]** despite the wide acceptance of the value of summative evaluation of practical work on teachers' pedagogical practises and students' learning experiences.

Ian Abrahams et al, in their comprehensive review on the assessment of experimental skills, elaborate the utility of direct and indirect methods for assessment. Each of these strategies has benefits and drawbacks. It is important to note that both direct and indirect methods can be used to evaluate practical science skills, and that relying too much on indirect methods will result in less reliable assessments **[31]**.

5.1 Direct assessment of practical skills (DAPS)

DAPS is the name given to any type of assessment that calls for learners to directly show a particular or general ability while manipulating real items such that it can be used to gauge their level of proficiency in that skill (For example, assessing a student for their skill of using a Microscope. Using DAPS, the skills required for manipulating a real microscope will be assessed, i.e., the student should place the slide on the stage, use appropriate objective lens to focus the specimen and focus the correct/expected region/portion of the specimen. The student will be credited for successful completion of all the tasks mentioned in this example).

5.2 Indirect assessment of practical skills (IAPS)

IAPS, on the other hand, refers to any type of assessment in which the level of proficiency of a student, once more in terms of a particular or general skill, is deduced from his or her data and/or reports of the practical work that he or she completed. (Considering the same example as in DAPS. If the student is assessed by IAPS based on the drawings of their observations under the microscope, the assessment will not tell whether the student drew their actual observations from the microscopic view or they just drew what they had observed or learnt previously)

6. The importance of assessing experimental skills

It is crucial to scrutinize the education system to make sure that students acquire essential life skills from the years of formal education. A meaningful set of "performance indicators" must be considered to characterise the totality of student experiences, not only the outcome of learning on individual students. Many a times, the application of the knowledge gained as students can only be observed decades later and measuring these effects of education can be challenging. A new assessment paradigm that illustrates the move to a student-centered approach allows students to study since it assumes that they are involved in their own learning. The conduct of laboratory experiments is important in the development of students' critical and self-critical faculties; creativity is fostered in them when they do not exactly adhere to instructions but instead draw their own conclusions at a particular point in their laboratory work **[32]**. Equally important is the right tool or methodology for assessment of the practical work. For example, Takeichi et al **[33]** formulated five-level evaluation criteria for the elements of experimental basis, theory, measurement, analysis and report. The organization of such mini-investigations increases the level of experimental research competencies of students and prepares them for independent research at college and university courses. The majority of teachers and researchers concur that engaging student in high-quality practical work at a younger age can aid in the development of important skills, a thorough knowledge of scientific inquiry, and conceptual comprehension. Learning about risk, hazard, and safe working is another benefit of practical experience, particularly in science.

7. Discussion

Although the term "practical skill" is currently used frequently in science education, it is rarely defined with the same level of accuracy as "subject content" understanding in science. Science is frequently less precise than some other areas, especially when it comes to the particular skill manifestations necessary at each age or level. Despite the expansion of a variety of practical skills in science, employers thought that the lack of practical experience and lab skills was a barrier to the recruitment of staffs with skills in STEM (Science, Technology, Engineering, and Mathematics). Therefore, more investigation is required to find out which scientific experimental skills are more crucial and deserving of evaluation than others.

A lot of research is available on how to build these more generic skills in scientific classes, but some skills are solely applicable to science. These include "higher order" thinking skills like argumentation, metacognition, and asking appropriate questions **[34, 35, 36, 37]**. A study by Nott et al. **[38],** demonstrates the importance of establishing and then evaluating the practical skills that awarding bodies and other assessment organisations want students to develop during their science courses. If not, evaluation may be reduced to a procedure where students are instructed on methods to score well on summative tests. The awarding organisations should therefore be as precise as possible about the practical skills that students should gain in science at different levels of education, as well as the subject matter knowledge that is expected of them.

Both IAPS and DAPS have advantages and disadvantages. It is indicated that while deciding whether DAPS or IAPS is more appropriate, DAPS is more suited if the objective is to evaluate students' capacities to carry out any specific practical tasks. However, if the objective is to evaluate a person's understanding of a skill or method, IAPS would be a better option **[39].**

We suggest adopting a technique of assessment that makes use of a rubric that has been created especially for a course in order to make it more convenient for implementation in the majority of Indian universities while taking into account their resources. The rubric assessment should be further investigated and enhanced in order to establish an assessment method that does not compromise an assessment instrument's core modalities, such as validity, reliability, feasibility, and acceptability. All of the staff members participating in student evaluation should comply with the methodology for it to be widely accepted by all the institutions across the country.

8. Conclusion

There is a rising need to make sure that school students acquire both laboratory confidence and experience in order to better prepare them for higher education and the workforce. Although it is obvious that it is impossible to teach the entire range of practical skills in science in high school, giving students the chance to gain experience with a respectable number of core practical skills will undoubtedly be far more beneficial for them than not giving them the opportunity. Designing suitable assessment strategies is equally crucial. Therefore, it is essential that instructors receive support in recognising the significance of hands-on experience in science education. Equally crucial is to be clear with the students about the abilities intended to be developed during a specific practical activity and the method of assessment of the acquired skills to make the science practical assessment more relevant. It is essential to adopt more contemporary alternative teaching and evaluation methods.

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Conflict of Interest

Authors declare that they do not have any conflict of interest.

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