Learning Through Inquiry and Investigation: A Critical Analysis of the Effectiveness of Practical Work at Undergraduate Level

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Abstract

Laboratories are a core requirement, in particular in science education for skill training and better understanding of concepts. The importance of good quality practical work is widely accepted for improvement of scientific skills and promoting the scientific culture amongst students, thereby leading to improved learning. Through this study, an effort was made to reflect and explore these often-raised concerns by assessing and mapping the current situation with inputs from stakeholders in developing students' knowledge and skills at the undergraduate level. A survey was conducted to identify and understand students' requirements, expectations, experiences and opinions regarding the practical work being done in undergraduate science laboratories in University of Delhi. The students' expectations in identifying the significant characteristics and requirements that demonstrate effective lab work were derived from this data.

Keywords: Efficacy of practical work, Inquiry, Experimental work

It is universally established that science education enables the learners to foster natural inquisitiveness and creativity, cultivate scientific temper and critical thinking, and understand the scientific processes and acquire the skills. Practical work is a major and characteristic feature of science education which can engage students to develop important skills and develop their understanding of concepts and process of scientific investigation. Hence the role of experiments in a good science curriculum is imperative and central to teaching and learning in science and that good quality practical work helps develop students' understanding of scientific concepts. For this reason, the

teaching and learning of a science program must balance and assimilate theory and practical as two essential and complementary aspects with a creative relationship of experiments, observations and theoretical inference.

Background

The teaching of science has received global attention since 1960 and what followed thereafter was a phase of concentrated and vital development in the science curriculum. The new curriculums laid more stress on the processes and procedures of science rather than science as a body of conventional facts. Subsequent to the effect of assessments carried out of the inquiry approach curricula that were implemented in UK, USA and in many developing countries in the 1960s and 1970s, a lot of research has been undertaken to study the impact on students' learning from doing experiments or watching demonstrations. The implementation of practical work to achieve effective and affective learning of science has been undertaken in numerous forms throughout history including “the discovery approach and the process approach” (Wellington, 1998).

The research conducted by Shulman & Tamir (1973) and Anderson (1982) suggests that the practical work in science education leads to improvement of scientific skills and promoting the scientific culture amongst students. The statement made by Solomon (1980) that “science teaching must take place in a laboratory and science simply belongs there as naturally as cooking belongs in a kitchen and gardening in a garden (p. 7)” emphasizes the relevance of practical work in sciences. Examining the aim of practicals, the studies performed by Kerr, 1963; Beatty & Woolnough (1994), Hodson (1993), Swain, Monk & Johnson (2000), suggest that positive attitudes in students' need to be stimulated and nurtured to improve their chances of continuing to study science during higher studies. According to Robert Millar (2004), 'practical work' is referred to "any teaching and learning activity which at some point involves the students in observing or manipulating the objects and materials they are studying" (Swain, Monk & Johnson, 2000). Lunetta et al., (2007) suggested that science laboratory provides a learning experience in which students interact with materials or with secondary sources of data to observe and understand the natural world. In India, the depth and expanse of vision of science education provided by the Education Commission chaired by Prof. D.S. Kothari led to several changes in science curriculum both in approach and content, during the last forty years or so in keeping with contemporary

worldwide trends in science education and shifting community needs.

According to National Curriculum Framework (NCF)-2005, an important criterion for validating a science curriculum is that it should engage the learner in acquiring the methods and processes that lead to the generation and validation of scientific knowledge and nurture the natural curiosity and creativity of the child. Hence the core mandate of the laboratory should be to provide opportunities to develop a spirit of enquiry in them and seek their answers from various sources.

The vision document for Indian Science 2010, INSA mentions that when it comes to science,

> No national scientific enterprise can be sustainable in the long term if it does not contain generous room for curiosity-driven research. While the technological outcomes and social benefits of basic science are almost always long-term and rarely predictable, such science creates and consolidates overall competence and intellectual diversity. (p. 6)

Although all these and other such studies have been conducted primarily to promote the natural curiosity of students' in science in the best possible manner, however, the problem of waning interest of students in science still persists and in fact is growing at an alarming rate.

It is broadly understood that practical work leads to improved learning, however, research proves that the manner in which the practicals are practiced, learning in students is not as expected and research studies tend to support this view. Osborne (1998) and Hodson (1991) claimed that the manner in which practical work is practiced in most countries is ill-conceived and unproductive and has limited role to play in learning science. Given that such a large proportion of time in science lessons is spent on practical work, it is important to understand the purpose and relevance of this type of activity as a tool for teaching and learning.

Objective of the study

The importance and rationale of practical work has been constantly deliberated, hence, as educators involved in teaching science at undergraduate level, a survey was conducted to reflect and explore the often-raised concerns by assessing and mapping the current situation with inputs from stakeholders in developing students' knowledge and skills at undergraduate level. The questionnaire was designed to identify and understand students' requirements, expectations, experiences and opinions regarding the practical work being

done in undergraduate science laboratories in University of Delhi. The purpose of this paper is to find the difference between rhetoric and reality regarding the effectiveness of practicals in science education at the undergraduate level and examine and discuss the role of practical work in the teaching and learning of science to increase the quality and effectiveness of practical work.

Methodology

The study uses stratified random sampling technique to select a representative sample out of the Maharaja Agrasen College student population. Primary data is generated from college student community through carefully structured questionnaire designed to collect information about their expectations, and opinions regarding the practical work being done in undergraduate science laboratories at University of Delhi.

The survey takes into account the opinions of students working in physics lab, chemistry lab, computer lab and electronics lab with the aim of determining whether the characteristics and expectations of effective lab work were same for all labs or different. Using an open-ended survey, students were asked to suggest the features they believe are essential to effective practical work in science laboratories. First question in the questionnaire caters to the attitude and expectations of students in science laboratories and seeks to know that why do the students think that practical work in laboratories is a core requirement in science education. The aim of other questions in the survey was to seek the students' responses based on their real time experience in laboratories. The last question in the survey questionnaire offered the students an open –ended opportunity to express their ideas about enhancing the effectiveness of practical work in science laboratories. The students' expectations identifying the significant characteristics and requirements that demonstrate effective lab work were derived from this data.

Key Findings

The following responses are culled from Maharaja Agrasen College students who participated in the survey.

Q1. Why do you think the practical work in laboratories is a core requirement in science education? (Students attitude / expectations towards Science Practicals)

1.1. Encourage learning skills

1.2. Understand investigation processes

1.3. Encourage enquiry and creativity
1.4. Learn science concepts
1.5. Encourage group work
1.6. Science practicals are fun

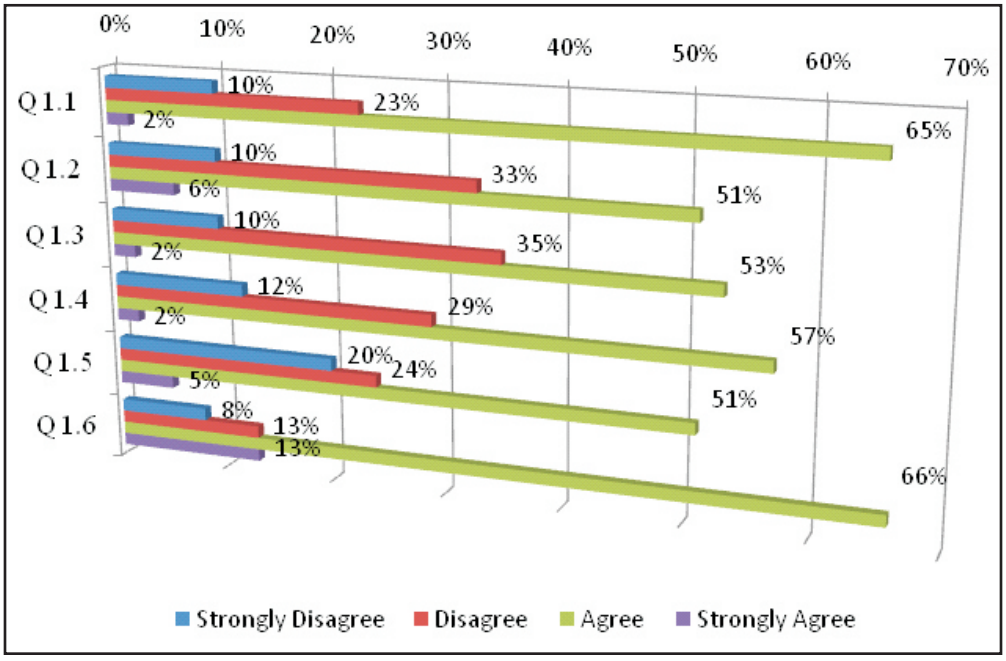

Figure.1 Participant Response to Q1

After the analysis of the survey's data on students' attitudes, it emerges that students' approach to practical work in science were generally positive. They believe that practical work supports their learning, is enjoyable, and leads to learning science concepts, understand investigation processes.From the responses, it is clear that more than 50% of students at undergraduate level expect the practical work in science laboratories to encourage learning skills, enquiry and creativity and encourage group work.

Q2. From your experience of working in a science laboratory, please comment on the following statements

2.1. It encourages learning skills
2.2. It helps to understand investigation processes
2.3. It encourages enquiry and creativity

2.4. It encourages group work

2.5. Science practicals are fun

2.6. It is important to understand science concepts, principles and learning outcome of the experiment before performing it.

2.7. Procedural directions should be provided for performing science experiments.

2.8. It is important to remember formulas and procedures of the experiment

2.9. I would prefer to find out why something happens by doing an experiment than by being told.

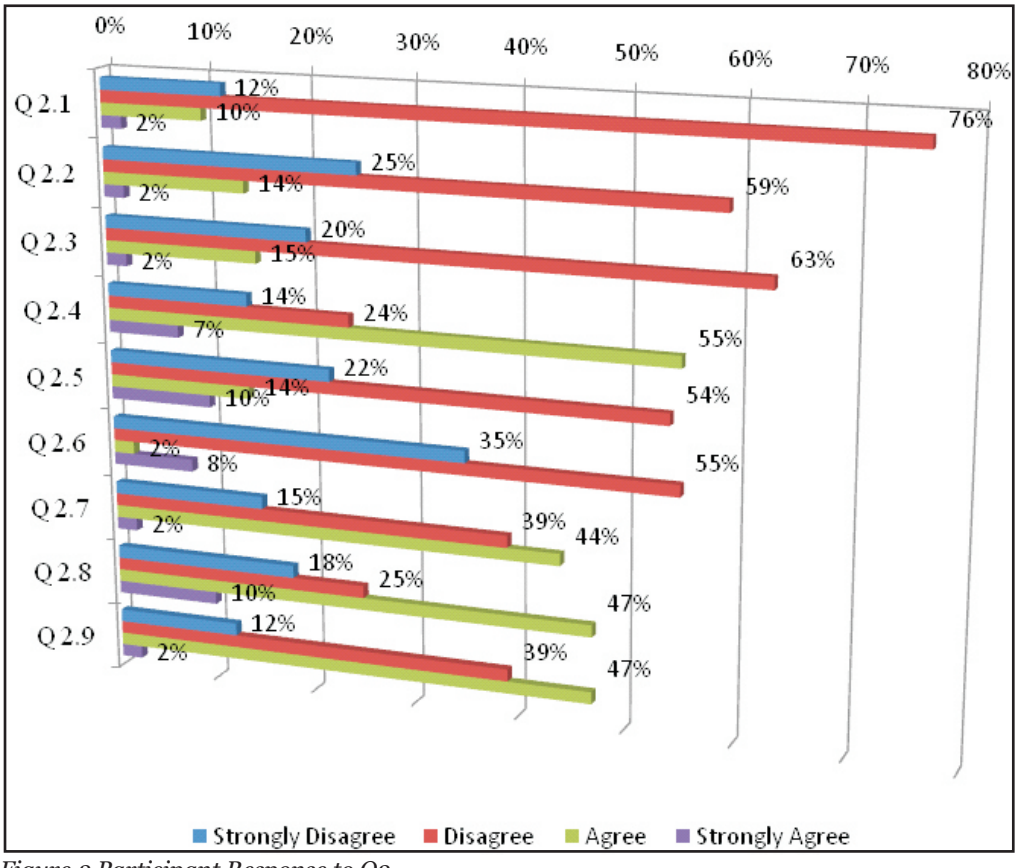

Figure.2 Participant Response to Q2

The survey results showed that the undergraduate science students at the University of Delhi had high expectations and strong beliefs about the importance of practical work but experienced low satisfaction with lab work as it did not improve their understanding of concepts of science much. The majority of respondents (> 50%) expected that laboratory work should be enlightening and encourages learning skills and enquiry and creativity. However, this opinion dwindled when they reflected about laboratory activities in their own respective courses. More than half of the students felt that their learning skills, understanding of the experiments and investigation processes was just fair or even poor. 55% students believe that it is not important to understand science concepts, principles and learning outcome of the experiment before performing it, rather majority students concentrate upon procedural directions to perform the experiment.

Q3. What problems do you experience when conducting experiments in laboratories in sciences?

3.1. More emphasis is on the theoretical concepts rather than on aspects of experimental design i.e. the collection, analysis, and interpretation of evidence.

3.2. Students do not get the opportunity to choose the method of investigation and recording of results, observation tables, analysis of results, all are prescribed in advance by the teacher/ book.

3.3. Rigid curriculum content

3.4. Pedagogy used generates limited curiosity

3.5. Inefficient technical support

3.6. Large practical batch size; limited opportunities to work and investigate independently

3.7. Insufficient time for students to reflect on their learning process or try something beyond curriculum.

3.8. Challenging, extended, and more open-ended, investigative practical tasks are rarely used to teach students about specific aspects of scientific enquiry.

3.9. Lack of consistent feedback to improve students' practical skills.

3.10. Lack of adequate resources and facilities in laboratories

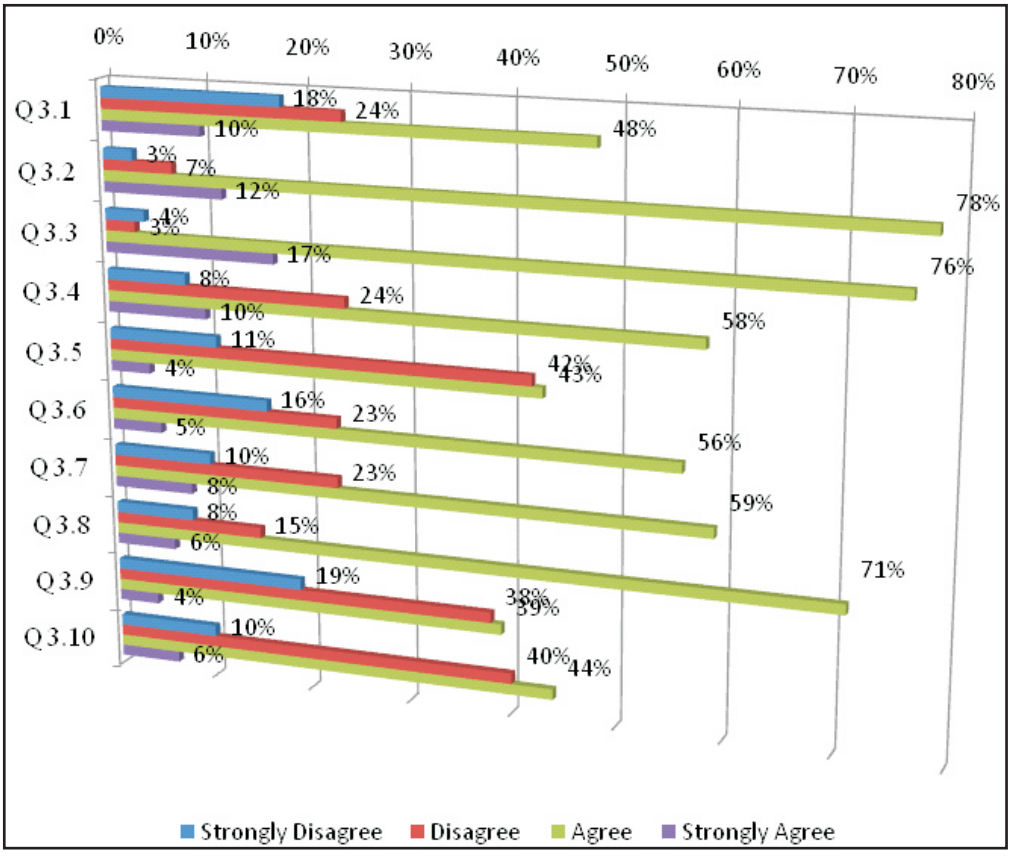

Figure. 3 Participant Response to Q3

When enquired about the various problems faced by students while working in science laboratories, more than 70% students felt that due to rigid curriculum, they do not get the opportunity to choose the method of investigation and recording of results, observation tables, analysis of results(all are prescribed in advance by the teacher/ book) with emphasis on 'recipe practicals'. Challenging and more open-ended, investigative practical tasks are rarely used to teach students about specific aspects of scientific enquiry.Also, students felt that large practical batch size results in limited opportunities to work and investigate independently and they hardly get any time to reflect on their

learning process or try something beyond curriculum due to paucity of time.

Q4. In science laboratories, how often do you do the following?

- 4.1 Explain and give reasoning behind an idea
- 4.2 Work on problems for which there is no immediately obvious method of solution
- 4.3 Represent and analyze relationships using tables, charts, or graphs
- 4.4 Use computers aids to solve exercises / problems
- 4.5 Work together as a class with students responding to one another
- 4.6 Work in pairs or small groups without assistance from the teacher

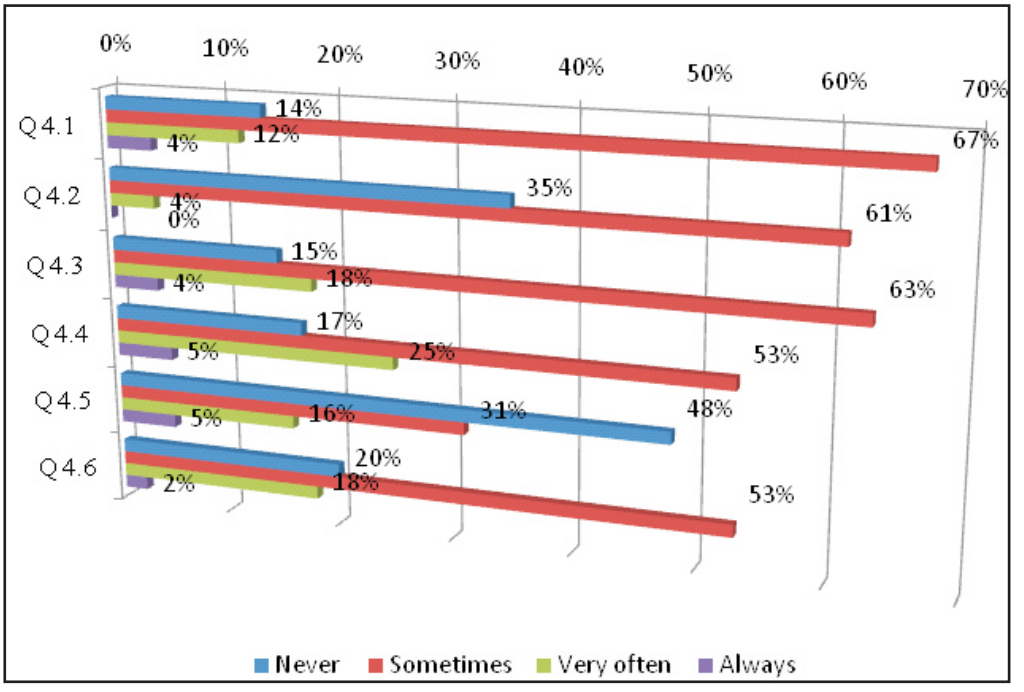

Figure. 4 Participant Response to Q4

The increasing prevalence and impending role of ICT in transforming both the practical and theoretical aspects of science teaching and learning cannot be overlooked as it offers a wide range of tools for information capture, processing and analysis, software for simulation of processes and carrying out 'virtual experiments, graphic tools, etc. Hence it is important that the studentsproperly are well-versed and updated to utilize the powerful potential of using ICT to support science learning. In the survey it was found that 53% students sometimes used computers aids to solve exercises / problems.

It is often argued that practical classes in science laboratories must accomplish much more than simply detailing the obvious unchallenged and unquestioned body of knowledge of science. Hence lab work requires a shift in focus towards ideas, facts and discussion that is more apposite to explain and give reasoning behind an idea and drive towards working on problems for which there is no immediately obvious method of solution. More than 60% students worked in this direction sometimes in the laboratories.

Q5. In what way can the effectiveness of practical work be enhanced in science laboratories?

5.1 More flexibility should be provided in terms of pace and place

5.2 Flexibility between online/offline mode of performing the experiment

5.3 Encouraging students to design and construct innovative projects/ models related to or beyond the curriculum.

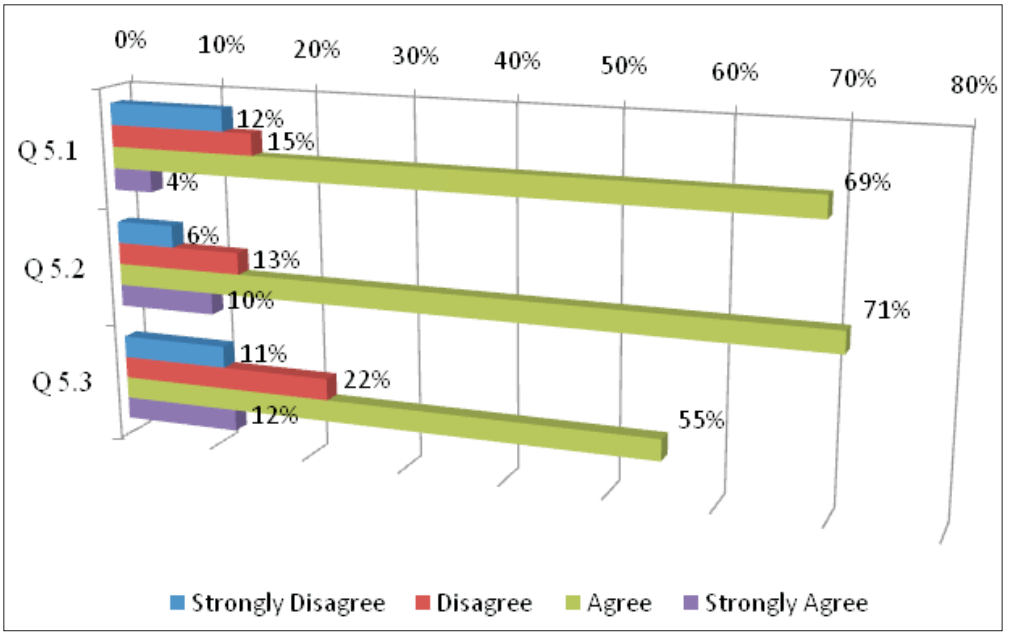

Figure. 5 Participant Response to Q5

In response to methods and mechanisms to enhance effectiveness of practical work in science laboratories, an overwhelming 65% -71% students suggested that more flexibility in terms of pace and place and online/offline mode of performing the experiment is required to increase opportunities and options available to learners and give them greater control over their learning through a variety of learning modes and interactions.

To further enhance the learning experience in laboratories, 55% students chose to design and construct innovative projects/ models related to or beyond the curriculum by applying the theoretical concepts acquired by them to design and construct innovative projects.

Conclusion

Opinions voiced by students in the survey to take stock of effectiveness of practical work in science laboratories at undergraduate level have produced compelling results. Although students' responses regarding their expectation and attitudes towards practical work in laboratories established that laboratory work has a central and distinctive role in science education in achieving the various learning objectives, however their responses based on their experience

of working in science laboratories reveal that these learning objectives are not being translated into actions. The feedback received from the students clearly provides the difference between rhetoric and reality regarding the significance of practical work as experienced by students in real time.

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