Effectiveness of laboratory practical for Students' Learning

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Abstract

Modules relating to engineering disciplines mostly comprise laboratory hands on practical in order to demonstrate the application of theory in practice. Guided sheet is usually followed by the instructor while carrying out the practical and students are allowed to work as a team by following the instructions. Since it is a common practice in almost all engineering laboratories, students' learning was investigated using two soil experiments in civil engineering technological programme in 2018. Interviews were conducted to search what students learn from the practical by recalling learned materials from sample of students after completion of the practical and the method adopted by the instructors were collected through the questionnaire. Analysis based on recalling learning showed that students remember observable aspects of practical task such as identification of apparatus and the testing procedure within one year but it does not assist them to learn theory and calculations though it has been totally covered during the practical lesson. It is noted that students highly involved in doing practical in laboratory rather than attending theory and calculation. Students' active involvement in learning before the commencement of practical with the assistance of the instructor, observing physical outcomes while doing and searching additional information at the end through internet have showed better results. Preset process is found partially effective and learning on theory and calculation need to be improved to make the process success.

Keywords: Laboratory practical, students' learning, recalling learning, effectiveness,

1. Introduction

Under engineering education, performance of laboratory practical takes major role in demonstrating engineering principles and theories in practice. Students who follow higher education in civil engineering discipline carry out practical in laboratory environment or in the field under the supervision of instructors to enhance their knowledge and skills on materials and methods which need to be applied for civil engineering industry. There are four laboratory experiments related to material of soil in second year program of National Diploma in Technology in civil engineering. Under this module, students are able to learn properties of soil as a material and the method of construction according to the standard and specification of earth work constructions by following lectures and laboratory experiments. Teacher who is in charge of this module designs the delivery of information to suit to the intended learning outcomes of this module and practical work at soil laboratory which is conducted as group work with five students in a group. In addition, guided laboratory sheet is given to each student to read and understand the total process of conducting practical at the beginning. Practical is supervised by the instructor while performing and observation sheet is certified at the end of the practical. Students are instructed to prepare and submit the report which is considered as a coursework in order to assess students' learning by marking them. Usually students are keen to carry out the practical as expected and submit the coursework during the allotted time frame. Feedback is given by marking coursework out of ten marks and corrections are noted for resubmission. Since this learning process spends considerable investment in terms of money and time, it is decided to investigate the achievement of students' learning by following the present process of laboratory practical and propose suggestions if necessary for its development.

2. Aim of Study

Aim of this study is to investigate achievement of students' learning in laboratory environment for practical works related to soil mechanics in civil engineering programme. Specific objectives are to;

1. Develop framework for analyzing students' learning from practical.
2. Analyze students' learning using developed framework.
3. Verify the effectiveness of practical by recalling learning.
4. Suggest improvements.

3. Literature Review

3.1 Learning from Laboratory Practical

Studying science is commenced by the students from ordinary school level understanding fundamentals of science and knowledge of science is gradually developed in advanced level classes engaging in laboratory learning environment. Roberts (2002) has highlighted that the quality of school science laboratories are to be concerned on the supply of people with science, technology, engineering and mathematics skills [1]. From the practical lessons, students are able to catch the information required for both carrying out the practical and gaining knowledge on theory and finally ending with expected results which are obtained scientifically through evidence. Laboratory instruction develops students' experimental skills, ability to work in teams and communicate effectively, learn from failure, and be responsible for their own results [2]. There is also evidence that students find practical work relatively useful and enjoyable as compared with other science teaching and learning activities [3]. A learning environment that allows active participation of students in the learning process makes it possible for the students to have control over their learning and this leads to improvement in students' learning outcomes [4]. Similarly, Tobin, Capie & Bettencourt (1988) explained that the laboratory learning environment allows students to interact physically and intellectually with instructional materials through hands-on experiences, and through minds-on and inquiry-oriented activities [5]. Laboratory activities appeal as a way to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science [6]. Getting students into the use of intended scientific ideas is important. What is urgently needed is an educational program in which students become interested in actively knowing, rather than passively believing [7]. Many research studies have been conducted to investigate the educational effectiveness of laboratory work in science education in facilitating the attainment of the cognitive, affective, and practical goals [6]. Laboratory sessions are an integral part of most science courses and the reasons for having them include: engaging students, converting theory into practice, affirming and illustrating concepts, gaining technical expertise, data and uncertainty analysis, report writing and research skills development [8]. There is a need to restructure traditional laboratory classes to enable students to learn by discovery, interact more effectively with peers and tutors, and begin to appreciate the excitement of performing experiments [9]. A recipe-based laboratory will provide the students with all of the steps they need to take to complete the practical, and while this will give them the chance to focus on technical expertise and analysis, it does not engage them in the experimental design process [10]. Tamer & Lunetta (1981) reported that laboratory handbooks do not provide students with expected opportunities to investigate and use the scientific inquiry method of teaching [11]. A number of subsequent studies showed that most practical tasks in science laboratory manuals provided students with little or no opportunity for open-ended or enquiry learning [12].

3.2 Laboratory Practical in Civil Engineering Education

Nuttgens (1988) suggested that engineering is almost the obverse of science. Most science-based courses include practical experimental activity in the laboratory [13], [14]. All technological courses related to engineering disciplines comprises with science based module with hands on practical in order to develop students' knowledge and skills. Applying science to everyday life requires both theory and hands-on practicum [15]. Engineering education is inconceivable without laboratory instruction and the educational goals of laboratory instruction are fully implemented in various types of hands-on laboratories and such an opinion still prevails among engineering educators [2]. The function of the engineering education is to manipulate materials, energy and information thereby creating benefit for humankind [16]. The overall goal of engineering education is to prepare students to practice engineering and, in particular, to deal with the forces and materials of nature [15]. Students are able to understand the scientific knowledge and its value as its phenomena is applied meaningfully for day to day requirements. Laboratory practical is necessarily to be designed to cover the expected learning outcomes of the particular modules such as identifying apparatus, carrying out specific way of practical, recording observations, learning theory, applying data to the calculation, finding results and interpreting them for the actual applications. Laboratory practical in civil engineering field is a good tool for teaching theory and demonstrate the theory for finding properties and selecting correct material or method in civil engineering applications. Aim of conducting this particular soil practical is also designed to give knowledge and skills required for carrying out the practical and applying its results in the civil engineering industry. Laboratory classes are integral part of an engineering course. In traditional laboratory a student follow a given procedure to obtain pre-determined outcome. Laboratories and fieldwork were clearly a major part of the engineering education experience [15]. From the beginning of engineering education, laboratories have had a central role in the education of engineers. While there has been an ebb and flow in the perceived importance of laboratory study versus more theoretical classroom work, it has never been suggested that laboratories can be foregone completely [16]. The purpose of laboratory work is well articulated as it is a place to learn new and developing subject matter as well as insight and understanding of the real world of the engineer [17]. Civil engineering students should be taught how to develop engineering judgment for the size of elements, expected dimensions, quantities, values and the sense of proportion which help to judge the results of calculation against reasonableness [18].

4. Methodology and Data Collection

1. Literature review was conducted to study the students' learning by following laboratory practical and framework was developed using the information collected.
2. Data was collected through questionnaire from two instructors (total number of practical was four) once completed the total soil practical in year 2018. The information collected was based on the method adopted by them at three stages such as before commencing, while conducting and after completing the practical.
3. Guided sheets used for carrying out practical were considered for identifying stated teacher's learning objectives. It contained name and objective of the experiments, list of apparatus, steps of procedure, observation sheet, brief description of theory including formulas for calculating results and few questions for guiding students to write discussion in satisfactory level.
4. There were 18 practical groups (total 78 students) who followed the practical during 2018 from which 22 students were selected by considering their previous performances to make the purposefully selected sample for this study. Qualitative research often focuses on a limited number of respondents who have been purposefully selected to participate because they have in-depth knowledge of an issue which are going to be studied. The purpose of purposeful sampling is to select information-rich cases whose study will illuminate the questions under study. They are rich in information because they are unusual or special in some way [19].
5. Once total practical classes were over, data was collected from purposefully selected sample by interviewing and recording information on structured questionnaire with regards to two selected experiments. Students' learning was evaluated by considering these 44 sets of information collected under five learning areas i.e. identifying apparatus, following standard testing procedure, applying theory and calculations and use of selected tests in civil engineering field in order to determine to what extent students have learned by conducting experimental practical.
6. Recall time was obtained using practical records from the register and date of conducting the interview to investigate the effect of remembering learning against the time duration.

5. Analysis and Discussion

5.1 Development of Framework for Students' Learning

Practical work, as several authors have pointed out, is a broad category that encompasses activities of a wide range of types and with widely differing aims and objectives [20], [21]. Following elements has been proposed the framework for evaluating the practical [20].

1. Teacher's learning objectives.

2. Design or select the particular task to achieve the desired learning objectives.
3. What the students actually do as they undertake the task.
4. What the student learn as consequence of undertaking task.

Designing a laboratory experiment without clear instructional objectives is like designing a product without a clear set of design specifications [15]. Therefore, the requirements of teacher's learning objectives and respective tasks (elements 1 and 2 above) were considered and derived by studying two guided experiment sheets of sieve analysis and proctor compaction tests. By observing the process of conducting practical it was found that structure of both guided sheets were same and instructors followed the given guide line while carrying out practical.

Table 1. Teacher's learning objectives

Teacher's learning objectives		Tasks undertaken
Doing practical work (Laboratory class)	Identify objects and observable and become familiar	1. Identify apparatus 2. Carry out practical 3. Record observations
	Learn theory and calculation	1. Apply theory and calculations
	Learn team work	1. Organize work as a team 2. Complete the practical 3. Clean the area
Reporting results (Coursework)	Learn writing report	1. Use of correct format 2. Sketch apparatus 3. Write procedure
	Learn concept and relationship	1. Calculate results 2. Compare results 3. Interpretation evidence 4. Discuss the experiment

Frame work presented in Table was considered for analyzing students' learning considering the way of carrying out the practical by the instructor using guided sheet.

5.2 Students' Learning

Practical work is generally effective in getting student s to do what is intended with physical objects, but much less effective in getting them to use the intended scientific ideas to guide their actions and reflect upon the data they collect [3]. Data collected from respective two instructors (sieve analysis and proctor compaction tests) is summarized as step by step under three stages i.e. before commencing practical, while doing practical and after completing practical.

Table 2. Before commencing practical

Sieve analysis	Proctor compaction
i. Allowed students to read and understand the given guidelines. ii. Collected their ideas by asking few questions. iii. Explained about soil and why this experiment is important. iv. Explained the objective and theory as per the guideline by showing information on the sheet. v. Explained the applications of the test in industry. vi. Allowed students to ask questions.	i. Explained the objective of the practical. ii. Discussed engineering applications in soil compaction. iii. Explained the theory by writing on the sheet. iv. Explained the purpose and importance of the test.

Table 3. While doing practical

Sieve analysis	Proctor compaction
i. Showed the apparatus ii. Explained the procedure again. iii. Observed the way of carrying out practical. iv. Allowed students to observe the soil particle distribution on each sieves. v. Observed how students recorded observations. vi. Allowed students to check the correctness of observations. vii. Allowed students to clean the place.	i. Introduced apparatus and showed them. ii. Explained how to do the practical for best performance. iii. Checked the students' performance. iv. Allowed students to clean the place.

Table 4. After completing practical

Sieve analysis	Proctor compaction
i. Allowed students to carry out calculations the way noted in observation sheet. ii. Certified observations. iii. Explained how to present the results. iv. Explained how to do calculations and writing coursework. v. Allowed them to search important information using internet for about 30 to 45 minutes.	i. Certified observation sheets. ii. Explained how to do the calculations. iii. Explained how to prepare the coursework. iv. Instructed to write discussion using the given questions.

Active learning is the process of having students engaged in some activity that forces them to reflect upon ideas and how they are using those ideas [7]. As qualitative study, following indicators are used to measure the students' participation.

Activity carried by the students alone – Highly participated (H)

Activity carried out by both instructor and students – Partially participated (P)

Activity carried out by the instructor – Not participated (N)

Data was collected from the instructor' questionnaire was summarized in Table to show the students' participation on each task in the developed framework.

Table 5. Students' learning on doing practical

Learning areas	Tasks covered in laboratory as group work	Sieve analysis	Proctor compaction
Identify objects and observable and become familiar	Identify apparatus Carry out practical Record observations	H H H	H H H
Theory	Learn theory and calculation	P	P
Team work	Organize work as a team Complete the practical	H H	H H

In this process, it can be said that doing practical is successful by the instructor as students managed the work as a team and arrived with desired observations. Coverage of learning theory and calculation was totally described by the instructor and students learn by listening without much involvement. Extent of learning received by individual students is not assessed while doing the practical. Measuring individual learning of practical is time consuming task for large group of students and the practical is usually designed as team work of students allowing learning by sharing knowledge through discussions in laboratory and at home. Engineering experiments are generally team efforts and this necessarily implies that all participants do not carry out the same activities [14].

Table 6. Students' learning at home

Learning areas	Tasks covered at home individually	Sieve analysis	Proctor compactio n
Learn writing report	Use of correct format. Sketch apparatus. Write procedure.	H H H	H H H
Learn concept and relationship	Calculate results. Compare results. Interpret evidence. Discuss results.	H H H H	H H H H

Though students highly covered all tasks at home, level of achievement cannot be assured in this process. Instructor may satisfy students' work by marking coursework or getting corrections through resubmission. Interpreting evidence, calculating, comparison and discussion of results are the main key learning areas which need to be kept in mind after completing practical. Recalling of learning as suggested in several research studies were undertaken to investigate the level of achievement received by the individual student using data from purposeful sample of students. Team work and writing report was not taken into account in detail study.

5.3 Recalling students' learning

According to the literature review, it is found that recalling experiment work is necessary to get the feedback for learning of the students. Using the time duration from the date of practical (in the register) to recalling learning was recorded in order to find the effect of remembering against the duration of learning. Since the practical was conducted once a week as rotation basis this duration is not equal to all students. Excel sheets were arranged to enter the collected data and individual student responses were noted. Identification of apparatus, experimental procedure, theory and calculations and use of the experiment in civil engineering field are considered as the main areas, which students need to keep as learning from the experimental practical. Time duration between the date of practical and recalling learning are presented along with the other learning information of 22 good students by covering 44 total records of soil practical. English letter was assigned from A to V (2 x 22 numbers) to a student when recording respective learning information.

Forgetting is the process of losing this information in memory or not being able to retrieve it even though the information is still stored [22].

5.3.1 Identification of apparatus

When interviewing, students were asked to state the apparatus used for the said two experiments and their answers were noted. It was noted that they recall the apparatus correctly while explaining the procedure. Therefore analysis is based on the identification of apparatus by the students while discussing the method of particular practical. Data is categorized as apparatus was Satisfactorily Identified – SI and
Not Identified – NI.

Table 7. Identification of Apparatus

Sieve Analysis			Proctor Compaction Test		
Recall Time Days	SI	NI	Recall Time Days	SI	NI
74	I		66	R	J
80	K, V	L	74	E, T	U
87	N		87	P, Q	
			107		V

101	F, H, E, G, S, U		115	K, L	
117		M	136	N	
150	A, B		171	F, H, G, S	
185	O		192	D	C
206	T	J	206	I	
220	P, Q, R		213	A, B	M
290	C, D		220	O	
Total	19	3		17	5

It is found that out of 22 students, 19 students and 17 students (average 82%) satisfactorily identified the apparatus used for these two experiments under the way of conducting practical. Though the recalling period varies from 66 days to 220 days, it does not affect for remembering learning. Practiced system using guided sheet and the instruction method have satisfactorily supported students for learning on identification of apparatus after performing the test. Effect of result of students J and M who did not perform well and students C and U who performed well in practical on sieve analysis may be due to the level of interest they paid.

5.3.2 Test procedure

Testing procedure mainly relates with the students activities carried out while performing the practical. When interviewing them, their explanations were clearly listened and noted step by step. The data collected was analyzed as Totally Explained (TE), Partly Explained (PE) and Not Explained (NE).

Table 8. Experiment procedure

Sieve Analysis				Proctor Compaction Test			
Recall Time Days	TE	PE	NE	Recall Time Days	TE	PE	NE
74	I			66	J		R
80	K, L	V		74	E		T, U
87	N			87	P, Q		
107				107			V
101	H, E, G, S, U		F	115	K, L		
117	M			136	N		
150	B	A		171	H, S		F, G
185	O			192	C, D		

206	J, T			206		I	
220	P, Q, R			213	B, M	A	
290	C, D			220		O	
Total	19	2	1		13	3	6

It is found that out of 22 students, 19 students and 13 students (average 73%) totally explained the test procedure of sieve analysis and proctor compaction respectively. Majority of students have learned the test procedure satisfactorily under this practical method. It is noted that students A, F and V did not perform well in both practical. According to the results, it can be said that hands on practice helps them to learn test procedure and keep them in mind without forgetting. Meaningful learning is possible in the laboratory if students are given opportunities to manipulate equipment and materials so that they are able to construct their knowledge of phenomena and related scientific concepts [6].

5.3.3 Theory and calculation

Aim of conducting soil practical is to investigate the properties of given soil samples by following the theory and calculation. Students get the actual work environment to conduct practical and learn how theory is applied and obtain the results by following the set of calculations. When collecting data from each student, time was given to explain the theory and calculation and record the explanations clearly. For the purpose of analysis the recorded explanations, they are categorized as; Satisfactorily Explained (SE), Partly Explained (PE) and Not Explained (NE).

Table 9. Theory and calculation

Sieve Analysis				Proctor Compaction Test			
Recall Time Days	TE	PE	NE	Recall Time Days	TE	PE	NE
74		I		66			J, R
80		K, L, V		74		E	T, U
87		N		87			P, Q
				107			V
101	S, U	F, H, E, G		115		K, L	
117			M	136		N	
150	A, B			171	S		F, H, G
185			O	192			C, D
206	T		J	206			I
220		Q	P, R	213	A, B	M	
290	C		D	220			O
Total	6	10	6		3	5	14

Student A, B and S learned well in both practical and students U and T learned sieve analysis test without relating to the recalling time. But majority of student (80%) did not learn well the theory and calculation in this process of conducting practical. This requires that teachers analyze more carefully the objectives of the practical tasks they undertake, and become more aware of the cognitive challenge of their students. It is thought that this phase allows the students to learn and experience science with greater understanding and to practice their metacognitive abilities in order to provide them with the opportunity to construct their knowledge by actually doing scientific work [6]. The laboratory courses in engineering education, are typically engaged in a general way to support existing ‘conventional' pedagogical practices which seem to be not so effective in developing the knowledge as well as skill of the learners [17].

5.3.4 Application in civil engineering field

Students, on the other hand, go to an instructional laboratory to learn something that practicing engineers are assumed to already know [15].

Table 10. Application in civil engineering field

Learning areas	Sieve analysis	Proctor compaction
Applications in civil engineering field		
Satisfactorily discussed	21 (95 %)	14 (64 %)
Not discussed	1 (5 %)	8 (36%)

More than 60% of student satisfactorily described the application of the test in civil engineering field and significant difference is noted in sieve analysis test. Additional experience received from civil engineering industry by the particular instructor may be supportive to gain high results in this area. Engineering graduates can benefit more when civil engineering courses are taught by instructors that have both academic and practical experience [18].

Data is analyzed basically by considering the students’ active participation on practical and recalling the learning. When considering the both method of analysis, following results can be determined.

1. Students have engaged in practical actively in the areas of identifying apparatus and carrying out procedure at the laboratory which assisted them to learn well in these two areas.
2. Students have not actively engaged in the areas of theory and calculation and have not shown good results on learning under them.
3. Active participations on hands on practical in the areas of identifying apparatus and describe procedure have showed good results on learning and keeping them in mind without forgetting. There is no relation to recalling time. Students do remember observable aspects of practical tasks, often many months or even years later, particularly when the event is a striking one [23].

In addition, it is found that there is a significant difference in the results of learning received by the students with respect to sieve analysis test. Additional activities carried out by this particular instructor can be summarized as follows.

1. Time was given for student to learn the guideline and understand the practical well and their knowledge was verified by asking several questions before starting practical. Many practical tasks of this type might be made more effective by designing them to stimulate the students' thinking before they make any observations [23].
2. Main idea about these practical is to learn the properties of soil. Practical was started after explaining the types of soils and the importance of carrying out the practical.
3. Students were allowed to observe distribution of soil particles well after the experiment in order to think about idea of the experiment.
4. Student have completed observation sheet individually by performing part of the calculations in the laboratory.
5. Time was given for students to search relevant information through internet after the practical at the laboratory to understand the test further and collect information for the discussion.

It is found that instructor had taken few steps to carry out the practical with active participation of students at three stages such as;

1. Before starting - to obtain the knowledge of soil and the importance of the experiment.
2. While doing – to think critically about the observed soil distribution.
3. After completing – to search additional information relevant to soil and the particular experiment to make good discussion.

5.4 Effectiveness of practical

The effectiveness of any type of a laboratory practical depends upon the learning objectives that are associated with the laboratory [2]. In this study, it is analyzed using the framework developed for students' learning in Table 1 and recalling learning received from Table 7 to Table 10 in order to verify the coverage of learning from practical by fulfilling the requirement of valuable two elements 'what students actually do' and 'what student learn'. Team work and writing report was not taken into account under this analysis.

Table 11. Effectiveness of practical

Teacher's learning objectives	What students actually do	What student learn Coverage of students population %
Identify objects, observable and become familiar	1. Identify apparatus 2. Carry out practical	82 73
Learn theory and calculation	1. Apply theory and calculations	20
Learn concept and relationship	1. Use of results in the industry	60

When considering the results received from recalling learning under this study, it is found that majority of students learn by following the practical except the areas of learning theory and calculation. It can be said that the procedure presently applied is not totally effective as main area of learning is not covered. Therefore suitable improvement (as given under suggestions) on theory, calculation and the use of results is required to make the practical process is more effective.

6. Conclusions

1. Teacher's learning objectives have been presented in the form of guidelines and students are able to learn them before starting practical.
2. Students have learnt well in the areas of identifying apparatus and carrying out the procedure by actively engaging the work in the laboratory. These learnings are kept in their minds for long periods as it may be a striking one to them.
3. Instructor can design the tasks orienting students' active involvement at the beginning by allowing them to learn using guideline, while carrying out by observing physical outcomes and at the end of the practical by searching additional information through internet, the better results can be achieved as shown in sieve analysis practical.
4. Process of conducting practical is partially effective as students are unable to learn the specific theory and the set of calculation. An additional activity is required in order to reinforce this particular learning area.
5. Purposeful sample (good students in the batch) was selected to collect learning by recalling. Similar results have been arrived for both analysis based on actual practice and the recalling learning.

7. Suggestions

In order to make the practical effective, it is suggested to add an additional activity as a formative assessment based on theory and calculation which has to be conducted in the classroom once the practical is over, with students' active participation and facilitation of the instructor [Anonymous, 2018]. If it is necessary to memorize any information well, engage in deep level processing which would involve asking as many questions related to the information as possible, considering its meaning and examining its relationships to the facts you already know (Human memory, Chapter 7, Friedrich Nietzsche, Psychology).

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