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Original Research Article

Evaluation and intervention of students' laboratory performance in chemistry graduating classes; Wachemo University, Ethiopia

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ABSTRACT

Background: The laboratory courses offer students the opportunity to gain manipulative skills, observational skills, and the ability to plan experiments and to interpret experimental data. The laboratory can be an excellent environment for active learning. It has long been considered useful to develop conceptual understanding, but some recent courses have been developed that rely heavily on laboratory experience, in contrast to conventional teaching methods, for the development of conceptual understanding of sciences. The primary purpose of this study was to assess laboratory perceptive of the graduating class students' of the department of chemistry and to engage them as active learners.
Methods: A total sample containing 20 students consisting of 14 males and 6 females were selected for the study. Four experiments were given to randomly selected participants in the respective strata and students were evaluated on the basis of different parameters.
Results: The findings of this research showed that almost all the sample students fail to correlate their theoretical accumulation with the practical performance.
Conclusions: So, severe works should be made on the various issues concerning the laboratory to be a unique learning environment to create well skilled students.

Keywords: Active learning, Laboratory intervention, Pre-laboratory, Post-laboratory

INTRODUCTION

For more than 100 years, laboratories have been employed for teaching and learning in the natural science disciplines.[1] Laboratory experiences have been found to promote problem-solving abilities, intellectual development, scientific thinking, and practical skills.[2-5] Laboratory work should achieve: ''enhancing mastery of subject matter, developing scientific reasoning, understanding the complexity and ambiguity of empirical work, developing practical skills, understanding the nature of science, cultivating interest in science and interest in learning science, and developing teamwork abilities.'' Unlikely, the traditional chemistry laboratories follow expository instruction and have been often described as cookbook-type laboratories.[6] Expository environments promote rote procedures which restrict students from forming an authentic understanding of the connections between the data they collect and the theories the data describe.[7]

In addition to lectures, the laboratory activities have an important and central role in the science curriculum. The courses in laboratory put forward students the occasion to gain manipulative skills, observational skills, and the ability to plan experiments and to interpret experimental data. The significant role of laboratory work is to help students to make links between two domains of knowledge: the domain of objects and observables and the domain of ideas. Therefore, learners can perform the experiments effectively at two levels: at the "doing" level and at the "learning" level.[1] Consequently, they need to have a variety of skills at both levels to experiment successfully. The "doing" level focuses on manipulative skills and observational skills whereas the "learning" level focuses on the ability to interpret experimental data and to plan experiments.[8] In addition, practical work promotes further aims, for example interest development, personality development, and enhancement of social competence.[9]

Laboratory as an excellent environment for active learning

The laboratory should help the students develop a broad array of basic skills and tools of experimental sciences and data analysis. While it is imperative that students have a broad experience with techniques using laboratory equipment, it is impossible to prescribe precisely which equipment should be used in all science laboratories. At the same time, it is advisable to allow students to make the use of many different types of laboratory apparatus to make observations. The laboratory should help students master basic science concepts. A growing body of research in science education indicates that a majority of students have difficulty in learning basic physical concepts in a course built around conventional teaching methods, textbook problems, and verification of experiments. These studies indicate that to improve learning, students must actively confront difficult concepts.[10]

Laboratory interventions

Intervention is a situation in which someone becomes involved in a particular issue or problems.[11] The principal focus of laboratory intervention should not be limited to learning specific scientific methods or particular laboratory techniques; instead, student in the laboratory should use the methods and procedures of science to investigate phenomena, solve problems, pursue inquiry and interests.[12,13]

Interest in using inquiry-based teaching strategies has increased in recent years as science teachers have become more critical about the efficacy of cookbook-type laboratory activities and indeed the purpose, practices, and learning outcomes of laboratory in general.[14] It is gradually being recognized that whereas cookbook laboratory can teach some laboratory techniques and skills or serve as visual aids for concept already studied, they are largely ineffective as a tool for teaching science concept.[15,16]

Evaluation of students' practical achievement during their university reside is one of the most imperative method to measure their skill and potential for what they build up. Students graduated with applied sciences are becoming the desire of the modern century to participate in new innovations that can transform human lives. So, this research has contributed to examine the practical accumulations and to fill in the existing gap in theoretical and practical achievements of third year students in the Department of chemistry, Wachemo University, Ethiopia.

Objectives

The general objective of this study was to evaluate laboratory understanding for the graduating class students' of the department of Chemistry, Wachemo University, Ethiopia and to engage them as active learners. In order to achieve this educational goal, the experimental phases should be designed to promote and require students' preliminary considerations and decisions concerning the laboratory procedure before they perform it. In this context the students learnt to recall theory and techniques, promote scientific methods of thought, make accurate observations, and interpret experimental results.

The research therefore had the following specific objectives.

- To examine the practical achievement of some selected students through conducting experiments;
- To let know reasons for students weak result during practical sessions;
- To reason out the possible solutions to minimize those barriers.

Having these objectives the research made an effort to answer the following research questions;

Question 1: Do students perform experiments more successfully and achieve higher learning outcomes by using a cognitive activating laboratory instruction?

Question 2: Are manipulative skills in a cognitive activating laboratory instruction developed as good as in a traditional laboratory instruction?

Question 3: Do students accumulate a good practical potential at the eve of their graduation?

Question 4: Could students overcome the current demand of their nation through their practical activities during their exposure to different governmental and non-governmental institutions?

METHODS

Population

The population of this study comprised selected male and female students of Chemistry department of the faculty of natural and computational sciences in Wachemo University, Ethiopia.

Even if many third year students were enrolled in the department of Chemistry at Wachemo University in 2015/16 academic year, sampling was important to observe the activity of each student in laboratory and to have adequate laboratory equipments during the experimental sessions.

Study design and sampling

The pilot study was conducted during the winter semester II, 2016 in the different laboratories of the Department of chemistry of Wachamo University. Initially, the existing laboratory instruction was revised and improved according to educational objectives and research results. A descriptive survey design was used for the study. The sampling methods used in the study were simple random sampling methods. Stratified sampling was assisted to represent all the students of 3^{rd} year Chemistry students based on their CGPAs and interest in the class. The total sample contained 20 students holding of 14 males and 6 females. Four experiments were given to randomly selected participants in the respective strata.

By using a pre-post design, the data were collected at the beginning and at the end of the practical course. Students were took a knowledge test, a lab skills test (own development), an attitude-towards-learning questionnaire, a self-assessment questionnaire, a subject interest questionnaire, a test for measuring deductive thinking and gave some demographic data in the frame of the pre-test. The post-test included again the knowledge test, the lab skills test, the attitude towards-learning chemistry, the self-assessment questionnaire, and the subject interest questionnaire.

Data collection

Data were collected on the basis of the following three phases.

Phase 1

It was a pre-laboratory phase that comprises and goes from the initial contact with the problem to the moment when everything is prepared to start the work with laboratory equipment.

Phase 2

It was the laboratory phase and it comprises the implementation of the planed laboratory (experimental or not) procedure with the associated data collection.

Phase 3

It was a post-laboratory phase that is concerned with data analysis and interpretation, evaluation of results and either elaboration of the conclusion or the reformulation of one or more steps of one or more of the three first phases.

Phase I (pre-laboratory evaluation methods)

Conceptual

Test: A test containing 10 questions from the different experiments they worked so far were given before the laboratory works. Students were evaluated on the basis of their score as excellent (8-10), very good (7-8), good (5-7) and weak (<5).

Procedural

Interview: Students were interviewed on the basis of different questions on a questioner to evaluate their understanding and interest to conduct the experiments before the laboratory sessions.

Attitudinal

Observation: The researcher had got some enquiry towards students' attitude to carry out laboratory works. The evaluation was on the basis of the interview.

Phase II (in laboratory evaluation methods)

Procedural: A procedure was given for each experiment and students performed all the experiments on the basis of the procedure without the assistance of the teacher. Each activity of the students in the laboratory were observed by the teacher and students performance were measured according to EVGW (Excellent, Very good, Good and Weak) evaluation method.

Attitudinal

Analysis of documents: A report was written by each group for each experiment. The reports were written soon after the completion of each experimental works with in the laboratory. This can help the teacher to recognize the students' reporting performance with in the laboratory. The evaluation were according to EVGW (Excellent, Very good, Good and Weak) evaluation method.

Phase III (Post- laboratory evaluation methods)

Conceptual

Practical test: At the end of the experimental works students know how during the laboratory reside were examined through a practical test. The test was given for each student regardless of their group.

Procedural

Interview: At the end of experimental works students were interviewed about the merits and demerits (problems) of the laboratory works and solutions to those obstacles.

Data analysis

Data were analyzed using simple descriptive statistical methods to generate amounts, frequencies and percentages.

RESULTS

Presentation of findings

Results of the study showed that only 40% of the total students sat for the examination scored the pass mark result (greater than 50%). Of this amount only 33.3% are female students. So, this result could be a good indicative for the weak perception of students towards laboratory courses and most students use laboratory courses simply for grade purpose.

As per the response of students towards the number of laboratory courses they learnt, an average of three laboratory courses were provided for each streams of chemistry (Analytical, Inorganic, Organic and Physical chemistry) and almost all students scored a good result (Good, Very good and Excellent) (Table 3). According to the questioner even if learning of laboratory courses was very important for them, they were not actively participated during the experimental works and this has affected them to have a negative attitude about the applications of practical sessions after graduation.

Table 1: Sampling students' profile in chemistry department.

Item	Alternatives	Respondents	
		Number	Percentage
Sex	Male	14	70
	Female	6	30
	Total	20	100

Table 2: Results of students test before laboratory works.

Items	Alternatives	No. (with score ≥50%)	Percentage
Sex	Male	6	42.85
	Female	2	33.33
	Total	8	40

Table 3: Questions designed for students regarding their attitude towards laboratory works.

No	Questions	Alternatives	Respondents in	
			No	Percentage
1	How many laboratory courses have you learnt?	3	-	-
		4	-	-
		5	-	-
		6	-	-
		More than 6	20	100
2	What was your average grade during the laboratory courses?	Excellent	3	15
		Very good	4	20
		Good	13	65
		Fair	-	-
		Poor	-	-
3	As a chemist do you think that learning of laboratory courses is as such important in consolidating your theoretical and practical knowledge?	Strongly agree	20	100
		Agree	-	-
		Disagree	-	-
		Strongly disagree	-	-
4	If your answer for question 3 is strongly agree and agree, what is your participation in the laboratory sessions?	Active participant	5	25
		Participant	10	50
		Spectator	5	25
5	What is your perception towards laboratory Learning?	Like	20	100
		Dislike	-	-
		Strongly like	-	-
		Strongly dislike	-	-
6	Do you believe that laboratory sessions in Wachemo University are interesting?	Yes	6	30
		No	14	70

7	Do you think that laboratory courses helped you in correlating with the theoretical courses you have taken?	Yes	20	100
		No	-	-
8	Do you believe that experimental works helped you in increasing your GPA?	Yes	20	100
		No	-	-
9	Do you think that the instructors and laboratory technicians are committed during the laboratory sessions?	Yes	10	50
		No	10	50
10	If your answer for question '9' is yes, how much your instructors and technicians are effective in advising your experiments?	Excellent	3	30
		Very good	5	50
		Good	2	20
11	Do you have well planned programs, flow charts and laboratory manuals before and during your laboratory sessions?	Yes	8	40
		No	12	60
12	If your answer for question '11' is yes, how many hour (average time) do you spent your time per week?	2 hours	2	25
		3 hours	6	75
		4 hours	-	-
		5 hours	-	-
		6 hours	-	-
13	Do your instructors have consultation hours for the laboratory sessions (out of the regular laboratory session)?	Yes	12	60
		No	8	40
14	If your answer for question '13' is yes, how many consultation hours per week does s/he has?	2 hours	12	100
		3 hours	-	-
		4 hours	-	-
		6 hours	-	-
15	What are the factors that you think to minimize students' interest towards actively participating during laboratory classes?	fear of chemicals	-	-
		lack of awareness	-	-
		incomplete laboratory	-	-
		time constraints	-	-
		All and other factors	20	100
16	Since you are an applied chemist and have the opportunity to join different factories; do you believe that the different experimental works you did so far can surely help you with in the industries?	Yes	20	100
		No	-	-

Table 4: Results of students' practical performance in chemistry laboratory.

Experiment No.	Group	No. of students	Results in (%)	Score
1	1	5	81	Very good
	2	5	73	Good
	3	5	71	good
	4	5	64	Weak
2	1	5	68	Good
	2	5	71	Good
	3	5	70	Good
	4	5	71	Good
3	1	5	74	Good
	2	5	73	Good
	3	5	62	Weak
	4	5	60	Weak
4	1	5	70	Good
	2	5	63	Weak
	3	5	67	Good
	4	5	61	Weak

Excellent (85-100%), Very good (75-84.9%), Good (65-74.9%), Weak (<65%)

The practical performance of the selected students was also evaluated and results showed that almost all students scored a good result (Table 4). However, since the experiments were selected from the various procedures they worked so far, this result did not indicate that the students have accumulated a very good laboratory knowledge that could help them in the different occupations they would hire. So, teachers, laboratory assistants and other concerned persons should work hard to enhance students' practical performance in laboratory.

In this research the reporting ability of students in laboratory were also evaluated and results showed that almost all students have a problem on writing a well-organized laboratory reports (Table 5) and this could have a negative effect on the students future endeavors. Therefore, students are expected to read different manuals on how to write laboratory reports to consolidate their reporting performance.

Practical examinations were given at the final session of the work and results were not as it was expected from graduating class students (Table 6). Students were asked about the main reasons to get a minimum score of the practical examination and almost all the students had similar answers. According to their feedback some of the reasons were; being grade oriented, weak understanding of the procedures, large class size and small laboratory instruments, delivery of many courses in a semester and weak attitude of the ministry of education towards laboratory courses.

Table 5: Results of students reporting performance in chemistry laboratory.

Experiment No.	Group	No. of students	Results in (%)	Score
1	1	5	72	Good
	2	5	70	Good
	3	5	72	Good
	4	5	69	Good
2	1	5	70	Good
	2	5	71	Good
	3	5	67	Good
	4	5	66	Good
3	1	5	73	Good
	2	5	73	Good
	3	5	66	Good
	4	5	68	Good
4	1	5	70	Good
	2	5	68	Good
	3	5	67	Good
	4	5	67	Good

Excellent (85-100%), Very good (75-84.9%), Good (65-74.9%), Weak (<65%).

Table 6: Result of students exam.

Student number	Group	Score (%)
1	1	67
2	1	66
3	1	62
4	1	59
5	1	70
6	2	66
7	2	71
8	2	65
9	2	60
10	2	62
11	3	67
12	3	67
13	3	64
14	3	61
15	3	65
16	4	65
17	4	72
18	4	68
19	4	64
20	4	63

Table 7: Questions designed for students regarding the merits of laboratory works.

No	Merits	Alternatives	Respondents in No	Respondents in Percentage
1	Enhances students participation	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	7	35
		Very high	13	65
2	Enhances preparation	Very low	-	-
		Low	-	-
		Neutral	5	25
		High	12	60
		Very high	3	15
3	Consolidates theoretical part	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	4	20
		Very high	16	80
4	Creating new foundation	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	2	10
		Very high	18	90
5	Enables grade inflation	Very low	--	-
		Low	8	40
		Neutral	8	40
		High	4	20
		Very high	-	-
6	Helps to know laboratory equipments	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	-	-
		Very high	20	100
7	Reduce confusion in classes	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	7	35
		Very high	13	65
8	Develop confidence	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	-	-
		Very high	20	100
9	Increase competition with others	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	18	90
		Very high	2	10
10	Enhance reporting	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	11	55
		Very high	9	45

Table 8: Questions designed for students regarding the demerits (interventions) of laboratory works.

No	Demerits (Interventions)	Alternatives	Respondents in	
			No	Percentage
1	Consume more time	Very low	-	-
		Low	4	20
		Neutral	10	50
		High	6	30
		Very high	-	-
2	Presence of hazardous chemicals	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	16	80
		Very high	4	20
3	Lack of organized instruments	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	15	75
		Very high	5	25
4	Enhance dependency	Very low	-	-
		Low	-	-
		Neutral	13	65
		High	7	35
		Very high	-	-
5	Small laboratory size	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	5	25
		Very high	15	75
6	Negative understanding	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	13	65
		Very high	7	35
7	Inapplicable in the country	Very low	-	-
		Low	-	-
		Neutral	10	50
		High	8	40
		Very high	2	10
8	Increases burden	Very low	-	-
		Low	-	-
		Neutral	4	20
		High	12	60
		Very high	4	20
9	Most students are grade oriented towards theoretical courses only	Very low	-	-
		Low	-	-
		Neutral	-	-
		High	15	75
		Very high	5	25
10	Involuntary teachers and assistants	Very low	-	-
		Low	6	30
		Neutral	12	60
		High	2	10
		Very high	-	-

At the end of experimental works students were interviewed about the merits and demerits (problems) of the laboratory works and almost all students had similar feedbacks (Table 7 and Table 8). Many of them agreed on some of the merits of laboratory works stated in table 7 and explained that the chemistry laboratory as a setting in which students work cooperatively in small groups to investigate phenomena, a unique mode of instruction, and a unique mode of learning environment.

DISCUSSION

Pre-laboratory test and interview

Lack of equipments, lack of chemicals, small laboratory size and large class size, presence of dangerous chemicals and lack of higher instruments in the University were some of the problems for the ineffectiveness of the students. Feeling secure, especially at the beginning, seems to reinforce student coping. The possibilities for trial and error without the risk of negative sanctions increase the will to accept challenges and to enhance development. The majority of students stated that *something* was missing which prevented learning from being adequate. This 'something' was expressed as a *significant* condition. The analysis revealed this something to be security. Absence of well-planned programs, flow charts and laboratory manuals before and during the laboratory sessions were also another problems.

In laboratory students' performance and post-laboratory evaluation results

These types of examination are the most valid approaches for assessing the *performance* phase, in which the students are involved in the conducting of and decision making within the experimental and observational phases. Traditionally, science teachers have been assessing their students' performance in the laboratory on the basis of their written reports, during or after the laboratory exercise. Unfortunately, this method of assessment provides only limited information regarding the students' behavior and performance during the practical exercise.

The main obstacle in using the *'practical examination'* approach is that its implementation is limited to those experiments that can be readily administered to students in a limited time, which obviously restricts both the scope and validity of the assessment. In addition, it can also have undesirable effects on the choice of experiments conducted throughout the year. In other words, in general, teachers limit their choice of experiment to those highly related to the type of experiment utilized in a practical test. There has been a change towards continuous internal assessment of practical abilities conducted and monitored by teachers in their school system in attempting to overcome these limitations and obstacles.

Analysis of students' response using factor analytic investigation, revealed that students' attitude towards the chemistry laboratory is not one-dimensional, as it was assumed to be for attitudes towards science. The following attitudinal dimensions were obtained: learning in the science laboratory, the amount of laboratory work, and the value of laboratory work. Importantly, it was found that the measure is sensitive to the type of the experiences to which the students are exposed, to differences in the type of streams that the students learn. In addition, a comparison of boys and girls regarding the various attitudinal dimensions revealed significant differences (boys work better than ladies). A question were raised to each female students participated in the laboratory work and their feedback was related to the socio-economic problems in the country.

It was found that in general, the students who were involved in the inquiry-type practical experiences developed a much more positive attitude towards learning chemistry in general and towards learning chemistry in a laboratory setting in particular compared to another departments. Nevertheless, the science education literature continues to emphasize that laboratory work is an important medium for enhancing attitudes, stimulating interest and enjoyment, and motivating students to learn science in general and chemistry in particular.

Laboratory activities have the potential to enhance constructive social relationships as well as positive attitudes and cognitive growth. Cooperative team effort is required for many laboratory activities. The less formal atmosphere (compared to the classroom), and opportunities for more constructive interactions between students and between students and their teachers have the potential to promote social interactions and thus create a positive learning environment.

An important and valid source of information regarding the different types of interactions that occur in Chemistry laboratories can be obtained by using measures that assess students' perceptions of the laboratory learning environment. If used properly, the laboratory has the potential to be an important medium for introducing students to central conceptual and procedural knowledge and skills in chemistry. Students who perform the various phases of inquiry are challenged by asking appropriate questions, finding and synthesizing information, monitoring scientific information, designing investigations, and drawing conclusions.

Interventions of practical laboratory works

Different methods and strategies have been adopted to assist students in the process of learning and understanding Chemistry. Unfortunately, students still perform poorly in chemistry laboratory courses in Ethiopian Universities, probably because many of them are yet to acquire the basic concepts and skills necessary for the learning and understanding the subject. The instructional methods and strategies commonly used in chemistry classes targeted the average students. Students at risk who are low performing are yet to attract the attention of chemistry education researchers.

The principal focus of laboratory intervention should not be limited to learning specific scientific methods or particular laboratory techniques; instead, student in the laboratory should use the methods and procedures of science to investigate phenomena, solve problems, pursue inquiry and interests. In this research students' feedback were collected about the problems/interventions during laboratory works (Table 8). The problems militating against the advancement of Science laboratory in general and chemistry in particular are mentioned in (Table 8).

The results of this study were in a good agreement with many reports towards students' performance in laboratory. Based on several authors different techniques concentrate on diverse dimensions of students' knowledge and competence. Thus, an adequate combination of techniques and instruments is needed for a comprehensive evaluation of students' learning in laboratory. As an investigation is more than the sum of the parts, an adequate evaluation of students' ability to perform investigations requires attention to concentrate on the synthesis of procedural understanding, rather than on individual concepts of evidence. The use of diverse evaluation techniques and instruments, either during the course or within the context of practical exams, and the collection of information from the diverse relevant elements is necessary but not sufficient to come to an overall judgement.[17]

Another point that is worth rising is that the evaluation of students' learning from laboratory activities can be continuous, periodical or both. Despite the fact that continuous evaluation has the advantage of giving immediate feedback to teachers and students[18].The research indicates that it is not a common feature of science teachers' practice. However, continuous evaluation is the one that best suits the purposes of formative evaluation and should be implemented whenever investigations are carried out. Due to their complex and holistic nature, a more global approach should be put into practice from time to time with summative purposes. The evaluation of students' learning can be carried out either by the members of the class - teacher and/or students- or by external examiners. Teachers' evaluation of their own students can be subjective, as it may be influenced by teachers' expectations.[18]

These results are also in alignment with findings in the USA also in Nigeria claiming that a greater degree of participation in the science laboratory resulted in an improved attitude towards chemistry learning in general and towards learning in chemistry laboratory in particular.[19,20]

CONCLUSION

The analysis regarding the students' perceptions clearly demonstrated that students who were involved in the inquiry-type investigation found the laboratory learning environment to be more open-ended, and more integrated with a conceptual framework. Moreover, it was found that the gap between the actual and the preferred learning environment on the various scales was significantly smaller in the inquiry group (Selected students participated in the laboratory). Also, with regard to the actual and preferred learning environment in the chemistry laboratory, the most predominant and statistically significant differences were observed for the open-endedness and the involvement scales, with the inquiry group having much more favorable perceptions.

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