Concept Mapping and Assessment of Virtual Laboratory Experimental Knowledge

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***Abstract*—: Quantitative assessment of learning is an important indicator of teaching practices apart from the depth and grasp of content being assessed. Fundamental objective of assessment approaches should help promote learner engagement and is appropriate to the diversity of learners that may be present in any class. Learning from online or virtual classrooms can be more challenging due to lack of direct personal engagement between the teacher and the student. There are various modes of assessment commonly adopted today and students may exhibit different levels of performance based on the assessment method. This paper focuses on cross-comparison of these techniques to learning of laboratory concepts in a virtual environment. Apart from comparison of the commonly used assessment methods such as multiple choice questions, descriptive questions, true/false statements etc., the work explores the best methodology to correlate assessment from a reliability and validity perspective to the learning objectives and measure the progress of individual students. Correlating the innate learning styles of students to assessment approaches is another outcome of this work. In addition, the use of concept maps to assess the relationship between various science based principles is characterized for two different experimental labs with N=147 students. The advantages to using assessment techniques from a 'time-to-assess' is also elaborated in this work.**

Keywords— Virtual Laboratories, Conceptual Learning, Concept Maps, Assessments, Educational Technologies

I. INTRODUCTION

Assessment is one of the key measures that provides a direct measure of quality of educational processes from teaching and depth of learning amongst students[1]. Examinations and asssessments should aspire to enhance a student's understanding of where they stand relative to others in a class and further assist them with improving their thinking as well as learning skills [2]. Most of the assessments done today fail due to lack of larger vision in terms of capturing what the student has learnt and how a diligently it could assist with promoting learning [3]. Some of the key questions that are often the focus of an assessment are if they serve as fair, reliable and valid instruments [4]. Reliability and validity are key in order to measure the conceptual understanding of the matter being studied, the pre-identified cognitive skills and level of assessment achieved and its correlation to the educational outcomes [5].

Ideally, an assessment should showcase multiple skills of students i.e. ability to describe concepts, their analytical skills, critical thinking, application of theory to practical scenarios through problem solving etc. More recently continuous assessment has been adopted and questionnaires have been used as a via media to assess the learning in different situations. A useful framework has been devised by Oliver (2000) [6], provides a comprehensive guide to the evaluation of the use of educational technology. The importance of assessment and its consequential influence on student's approaches to their learning has been described elsewhere [7]. Assessments portray how much learning happens with how i.e. their approach, and what i.e. the content students learn. It is interesting to note that students also have preferences for assessments and their learning methodologies are affected by the types of assessments.

The three objectives of evaluation are described by Harland (1996) [8]. They are: evaluation for decision making or action, evaluation for understanding (enlightenment) and evaluation for control. Most evaluations may have one or more of these three elements and their emphasis may vary as well. The most common types of evaluation include questions with multiple choices, true or false statements, descriptive questions etc. There has been some reservation that when multiple choice questions (MCQs) are used for assessment, it does not reflect the deeper understanding of topics amongst students [9].

Most of the researches on assessments have shown its strong influence on supporting learning through individual empowerment [10]. Choosing an assessment technique depends on the content to be assessed since student achievement in relation to certain targets can be more appropriately measured by using specific techniques [11]. Assessment should test a) course related knowledge and skills b) learner's attitudes, and c) learner reaction to instruction.

This study is contextualized for the evaluation of student's learning goals through existing assessment practices. When educational technologies such as Virtual Laboratories are being used as an every day learning tool, it is important to understand how best assessments work not only for virtual

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learning environments, but also for experimental concepts, protocols and techniques. Key contributions of this work include comparison of assessment techniques from reliability and validity perspective and integration of concept mapping as an assessment tool.

II. VIRTUAL LABORATORIES

Amrita University has pioneered development of Virtual Laboratories (VLs) in an attempt to bridge the gap in availability of large infrastructure in higher educational institutes to study science and experimental phenomena [12]. The primary areas of work from the institute included building of VLs in multiple areas of science and engineering. Every experiment in the VL platform has six tabs i.e. description of theory, procedure, self-evaluation prior to attempting the experiment, a simulator followed by assignment and references. The simulator plays a central role in the learning process. The simulators can be of three types i.e. 1) animation based simulator, 2) simulation of the experiment or 3) remotely triggered experiment. Videos with voice over descriptions assist with viewing of experiments as it appears in the real world. The key aspects of using VLs include experimental phenomena can be explored through ample visualization. The platform also provides flexibility to access VLs anytime, anywhere apart from allowing students to attempt the self-evaluation questions any number of times. Two specific physics experiments were used to study the impact of assessments. These particular experiments were chosen for they required deeper understanding for successful completion of assessments.

A. Compound Pendulum Experiment

The compound pendulum experiment shown in Fig. 1 is done to estimate the acceleration of gravity in an atmosphere, the radius of gyration and moment of inertia about an axis perpendicular to the plane of oscillation. In this VL experiment, one is able to change the length of the scale suspension and the atmospheric environment or gravity, such as if the experiment were done on Moon, Jupiter, Uranus etc. Needless to say when this experiment is done in a real laboratory, gravitational factors are difficult to change and therefore study.

Figure 1: Compound Pendulum Motion in Moon

The experiment allows students to explore their conceptions of *acceleration* such as their experience with driving cars. Assessments could then be created to demonstrate the limitations and inconsistencies of their conception and to guide them towards reconstructing their conception in order to resolve their dilemma. Since compound pendulum oscillation is affected by gravity, the values for moment of inertia etc. obtained from theory could differ from those obtained in physical lab. Thus with respect to the assessment of understanding the physics behind the compound pendulum, the mathematical equations governing the phenomena alone do not provide complete understanding of reality.

B. Heat Transfer by Conduction

The experimental objective of this experiment was to find the thermal conductivity and thermal resistivity of materials. A heat conduction apparatus shown in Fig. 2 is used to supply heat through guarded hot plate method. From theory,

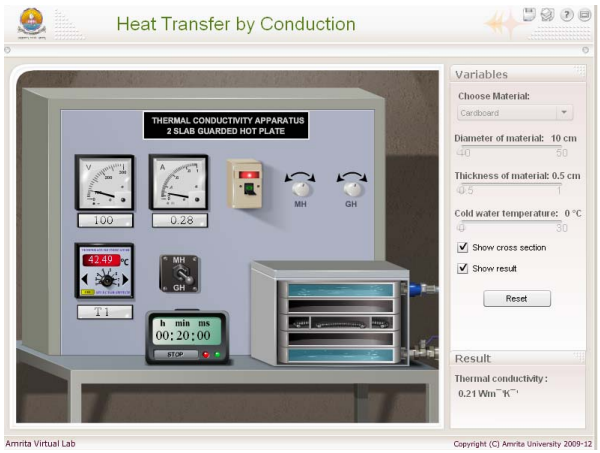

Figure 2: Simulation of Heat Conduction Apparatus

the rate at which heat is conducted through a slab of a particular material is proportional to the area A of the slab and to the temperature difference ΔT between its sides and inversely proportional to the slab's thickness d.

The amount of heat Q that flows through the slab in the time t is given by

$$\text{Rate of conduction } \frac{Q}{t} = \frac{kA\Delta T}{d}$$

It is to be noted that the amount of heat i.e. the value of Q can vary in an experimental situation due to a number of factors and relying on theoretical calculation may not mimic reality. While doing the experiment students are ignorant of the precautions taken for this experiment. The VL simulation provides information visually regarding how the conduction exactly occurs through a particular material.

III. RESEARCH METHODOLOGY

In this study, 147 undergraduate students participated. All students were from the biosciences or computer science and engineering branches. All students were required to study in the first year of their respective programs. None of the students had any exposure to these experiments prior to this study. There were four steps to our research study.

1. In the first step, the targeted student underwent a test of their learning styles by participating in a questionnaire called 'Index of learning' developed by Felder et. al [13]. The data was collected online and the test duration lasted approximately 30 minutes.
2. In the second step, students were exposed to both Physical Lab (PL) and VL experiments and were asked to study the theory; procedure etc. explained the theory behind the experiments without any visuals or visit to real labs.
3. In the last step, students that had gone through both PL and VL were assessed using four different types of questionnaire. These included Yes / No questions, MCQs, Descriptive questions and Essay type questions. A parallel on the design of the questionnaire was based on Bigg's [14] and Scouller and Prosser's models [17].
4. The students were then exposed to a unique questionnaire that had concept maps and required the students to draw the relationships between various concepts.

The grading given to the types of question varied. The Yes/No questions had 1 mark each, The MCQs carried 2 marks while the descriptive and essay type questions carried 5 marks and 10 marks respectively.

Data was collected from four types of questionnaires where undergraduate engineering students in the first year of their study had physical labs and virtual labs as part of their curriculum. To measure the internal consistency and reliability of the questionnaire, we tested Cronbach's alpha [18]. Internal consistency describes the extent to which all

Table 1: Example Questions in Questionnaire Addressing Various Types of Assessment

Construct	Measurement Item		Mean	SD	Cronbach's Alpha
MCQ Type	1.	In conduction, heat is transferred by means of	2.78	1.42	0.45
	2.	Determine the heat flow across a plane wall of 10 cm thickness with a constant thermal conductivity of 8.5 W/mK when the surface temperatures are steady at 100°C and 30°C. The wall area is $3m^2$?	2.75	1.43	
	3.	Compound pendulum differ from simple pendulum by its	2.01	1.42	
	4.	A pendulum takes 4 seconds to swing in each direction. Calculate the length of the pendulum?	2.95	1.45	
Descriptive Type	1.	What you mean by conduction?	2.20	0.85	0.76
	2.	Determine the heat flow across a plane wall of 10 cm thickness with a constant thermal conductivity of 8.5 W/mK when the surface temperatures are steady at 100°C and 30°C. The wall area is $3m^2$?	2.34	0.89	
	3.	What is the difference between compound pendulum and simple pendulum?	2.29	0.88	
	4.	A pendulum takes 4 seconds to swing in each direction. Calculate the length of the pendulum?	2.01	0.84	
Essay Type	1.	Explain the process of heat transfer by conduction using diagrammatic representation?	2.74	0.74	0.58
	2.	Determine and explain the heat flow across a plane wall of 10 cm thickness with a constant thermal conductivity of 8.5 W/mK when the surface temperatures are steady at 100°C and 30°C. The wall area is $3m^2$?	2.63	0.75	
	3.	Explain and distinguish the theory behind compound pendulum and simple pendulum?	2.61	0.71	
	4.	A pendulum takes 4 seconds to swing in each direction. Calculate the length of the pendulum and explain its theory?	2.57	0.77	
Yes/No Type	1.	Does heat is transferred by collision of molecules through convection process?	2.17	0.38	0.01
	2.	Does heat of about 0.36 can flow across a plane wall of 10 cm thickness with a constant thermal conductivity of 8.5 W/mK when the surface temperatures are steady at 100°C and 30°C and wall area is $3m^2$?	2.22	0.47	
	3.	Is compound pendulum and simple pendulum are different by its centre of mass?	2.42	0.44	
	4.	A pendulum takes 4 seconds to swing in each direction; the length of the pendulum can have 0.52m?	2.33	0.45	

the items in a test measure same concept or construct and hence connected to inter-relatedness of the items within the test. Reliability estimates amount of measurement error in a test. Table 1 gives the details of the results from various assessment techniques.

Concept maps express the most relevant relationships between a set of concepts with clarity. By linking concepts through phrases and forming propositions, the relationships are expected to be defined. The process of building a concept map includes summarizing the minimum number of words with which a concept can be represented and linking these words concisely using verbs etc. In this study we were prepared a question model based on concepts maps for two experiments. The compound pendulum experiment was defined using 15 concepts (Figure 3), while the heat transfer by conduction was described in 12 concepts (Figure 4). Both concept maps included definition/logical deductions, equations underlying the physics of the experiment and operationalization of experiments or modeling procedures.

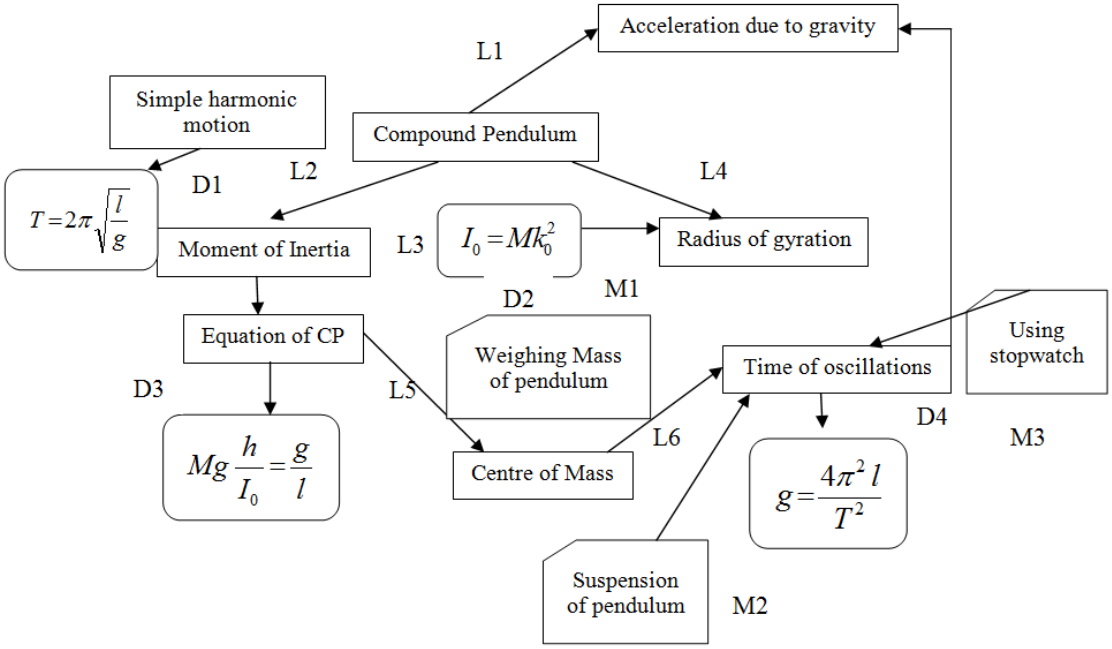

Figure 3: Concept map for Compound Pendulum with n=15 concepts. L-definition/logical deductions, D- Equations used for the experiment, M- Operationalizing experiments/modeling procedures.

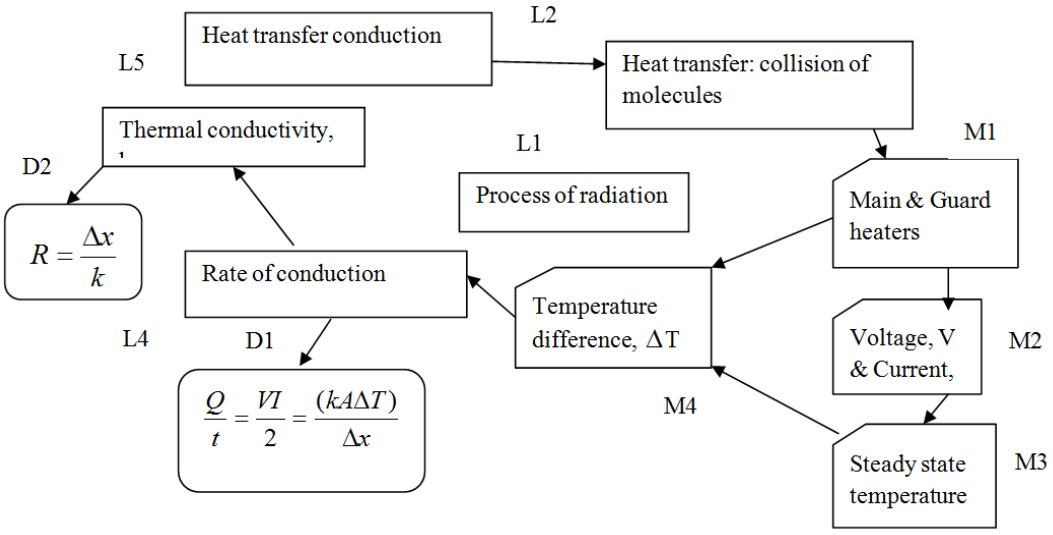

Figure 4: Concept map for Heat Transfer by Conduction with n=12 concepts. L-definition/logical deductions, D- Equations used for the experiment, M- Operationalising experiments/modelling procedures.

IV. RESULTS AND ANALYSIS

A. Deciphering Student Learning Styles

Index of Learning styles (ILS) questionnaire has 48 questions that categorize students based on their predominant behavior of learning [19]. Some of them may be more visual while others may be more verbal or intuitive in nature. These styles are catogoried in complementary pairs. For example the questions that measure active and reflective styles are referred to as ACT-REF, while other measures are related to sensing or intuitive nature is termed as SEN-INT, and those that are visual and verbal are termed as VIS-VER. The final pair relates to students being sequential and global i.e. SEQ-GLO. Each of these learning styles are graded each on a scale of +11to -11. The Fig. 5 shows the learning styles distribution of participants. For example, in VIS-VER pair, a score further along the negative axis indicates more of a visual learning style, while that along the positive axis indicates more of verbal styles. Reliability and construct validity of the ILS learning styles measurement has been document [20]. Intial response of participants from Index of learning shows that most of them are in the VIS-VER category. In other words, they learn better when information is shared in the form of visual representation with verbal explanations.

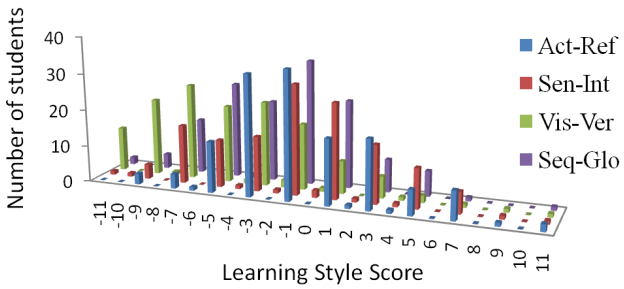

Figure 5: Student Learning Styles from ILS questionnaire

B. Comparison of Data Assessment Methodologies

Results from Table 1 show that value of Cronbach's alpha, 0.76 is high for descriptive type questionnaire, while the MCQs and Essay type questions had 0.45 and 0.58 respectively. This indicates that MCQs have limited validity for measuring the application of knowledge, and most questions ignore the whole picture [21]. Although there have been several suggestions to improve the quality of MCQs [22, 23], none of these suggestions have enhanced the power of MCQs to test cognitive skills or assess competence [24]. Here we can change the level of difficulty easily by providing options that may be similar, yet not exactly identical to the correct answer, while maintaining the same degree of difficulty [25]. The Yes/No questions had the lowest Cronbach's alpha indicating worst reliability. Compared with MCQ, descriptive questions were much better due to the following reasons: 1) These questionnaires focus on key elements of the experiment that includes main procedure to solve the answer 2) The quality of information demonstrated in the answers reflect broader aspects of student's learning 3) They emphasis is on all rounded information rather than just the final answer and 4) It helps characterize individualistic learning rather than those represented by groups. [26]. In case of essay type, although the students have to freedom to answer very elaborately, the tendency to not answer to the point is high. Essay type questions assess if students have a general idea about a concept. The main disadvantage to essay type questions are that they are time consuming, although they could be more useful in some cases and eliminate guessing. Yes or No type having very low values of Cronbach's alpha due to lack of detail and depth about the concepts displayed from the assessment. Based on the analysis, Yes/No type questionnaire generates incomplete or irrelevant data is highly discouraged from use as assessment for conceptual understanding.

Figures 6a and 6b show the score attained by the participants from two experiments. The results show that most of the students answered well in descriptive type questionnaire rather than MCQ in both PL and VL for two experiments. Also here the students scored well in visual based questionnaire in VL and PL, but is less in PL. This is due to the fact that simulations allow students to control the parameters of the experiment resulting in maximum knowledge transfer and wider grasp of concepts with application [27, 28].

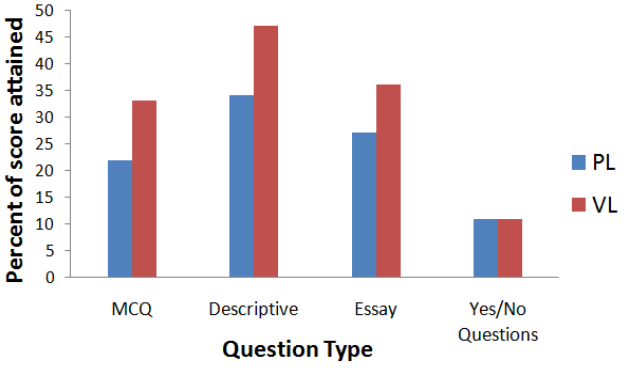

Figure 6a: Questionnaire Scores for Compound Pendulum Experiment

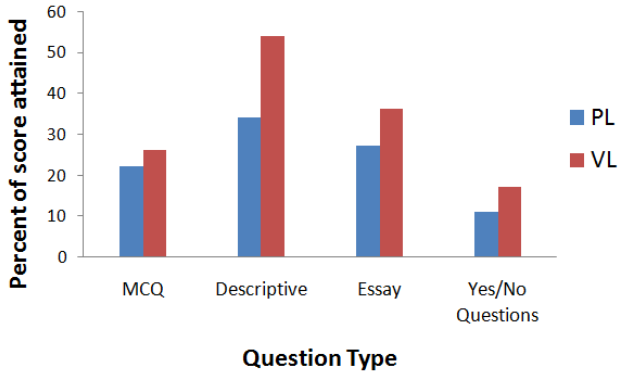

Figure 6b: Questionnaire Scores for Heat Transfer by Conduction Experiment

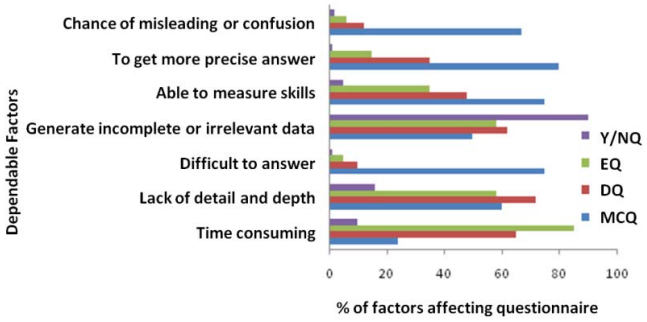

Figure 5: Factors Indicative of Issues with Assessment Questionnaire

It is important to consider the difficulty in understanding of the questionnaire. Fig. 5 lists the most common challenges of the questionnaire. The data shows MCQs have the larger probability to cause confusion or mislead the students towards their answers. In case descriptive type there exist lack of detail and depth. The Essay type questions however take the most time to complete. The ratio of average measurement of skill to the amount of difficulty was highest for descriptive types of questions compared to the rest.

When concept maps were used for assessments, the Cronbach's alpha was approximately 0.75, which is almost equal to that obtained from the descriptive type of questions. The added advantage of using this methodology is that it is far less time consuming, yet so reliable. Also the percentage of scores students attained by using concept map questionnaire was about 65% for PL and 85% for VL batches of students respectively. This is identical to the descriptive type questionnaire as well.

On looking at the time to complete individual assessments, the Yes/No questions took the least time. This was followed by MCQs and concept map assessments. The highest time taken was for Descriptive type of questions as well as the essay type. The key finding of this work is that concept map assessments can cut down the evaluation time significantly while maintaining high reliability and validity.

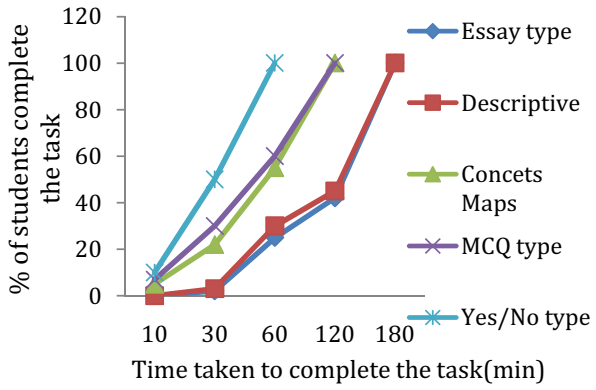

Figure 7: Time to Complete Individual Assessment Instruments

V. CONCLUSION AND FUTUREWORK

Current evaluation methods do not map the learning objectives to the assessment technique. The resulting assessments techniques are thus insufficient to gauge the deep learning promote student empowerment through assessment. This work focused on deriving optimal assessment technique to educational technology such as Virtual Laboratories. Questions in MCQ or Yes/No format can quickly assess student knowledge, however is found unreliable to judge laboratory protocols and procedures. Even if the final answer is correct, several students took to guesstimating the answers. Amongst the descriptive and essay type of questions, the descriptive type proved to be more reliable and valid. The descriptive questionnaire allowed students to arrive at the right conclusions systematically. On the other hand, the essay type questionnaire, allowed the students to elaborate their answers rather than presenting the theory alone. On examining two prime characteristics of questionnaires, i.e. its ability to measure skills as well as the difficulty to answer the questions, the descriptive type of questions proved to be the most effective. One significant disadvantage found is the time to assess from a descriptive questionnaire. In the work, concept map based questionnaire were found to be an optimal technique to assess, with it being highly reliable, quick to assess and reflect deeper learning amongst students.

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