Educ Inf Technol (2017) 22:2825–2855
DOI 10.1007/s10639-017-9626-x

Augmented reflective learning and knowledge retention perceived among students in classrooms involving virtual laboratories

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Received: 5 January 2017 / Accepted: 12 July 2017 / Published online: 3 August 2017

Abstract Learning theories converge on the principles of reflective learning processes and perceive them as fundamental to effective learning. Traditional laboratory education in science and engineering often happens in highly resource-constrained environments that compromise some of the learning objectives. This paper focuses on characterizing three learning attributes associated with reflective learning i.e. metacognition (M), analogical reasoning (A) and transfer of knowledge (T) and assessed college laboratory education blended with ICT-enabled virtual laboratories. Key contributions of this study include: 1) Development of assessment of MAT attributes using a combination of multiple choice questions, True/False statements and descriptive questions 2) assessment of conceptual learning occurring in the laboratory environment and of learning attributes using Virtual Laboratories (VLs) in classroom education. Feedback data indicated using virtual laboratories in classrooms for training students before using physical laboratories demonstrated a significant improvement (>100% change) in learning in comparison to physical laboratories without VLs. We also show using VLs as pre-lab or post-lab exercise augmented reflective learning and information retention among 145 students in this blended learning case study, compared to an independent control group of 45 students who had no virtual laboratory training.

Keywords Blended learning · Virtual laboratories · ICT · Assessment · Classroom education · Retention of learning

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1 Introduction

Higher education curricula in Science and Engineering are structured to provide students with a blend of theoretical and practical education. Theoretical components emphasize overall knowledge while practical education emphasizes skill training applicable to the selected field of study. There is growing concern on the shortcomings of current educational practices (Michael et al. 2010).

Sciences require understanding and the practice of reflection enhances visualization of relationships resulting in improved retention of ideas or concepts. The relevance and impact of reflective thinking have been recorded across many studies with diverse audiences (Bubnys and Žydžiūnaitė 2010; Colomer et al. 2013). To understand what assisted reflective thinking, Van Mannen (Manen 1977) & Mezirow (Mezirow 1997), Jacob & Murrays (Jacobs and Murray 2010) indicated several levels of hierarchy that include critical thinking, understanding and habitual reflection, reasoning etc. A study had (Peltier 2006) summarized reflection as learning meanings from experiences.

Multiple studies have investigated how computer simulations have often been used to enhance traditional instruction for Science, Technology, Engineering and Mathematics (STEM) education (Colomer et al. 2013). Using simulations to augment visualization as well as interactivity, and engaging a student's attention to concepts with exercises connected to learning have shown significant benefits in the learning outcomes (Rushton and Lahlafi 2013). It has been suggested that institutions could allow better access to virtual and online laboratories as collaborative learning environments (Bourne et al. 2005). To quantify augmented learning outcomes, measures through test scores, student engagement with reading material, sense of community among learners and reduced drop-out or failure rates have been employed. (Nguyen 2015).

In many developing countries, that have large and growing populations of students pursuing higher education and a limited number of educational institutions with required facilities, resources to match the needs are often inadequate. Educational resources include availability of trained teachers, laboratory infrastructure to support a large variety of experiments and the facilities required to run them on a frequent basis. Even in well-equipped institutions in India, the standard practice in undergraduate and often postgraduate laboratory education is to have groups of students perform a single experiment in the lab.

Although, collaborative problem-solving with a team enhances learning, often in a laboratory environment, grouping students to perform experiments results in incomplete training of individuals due to shared resources-time for experimentation. This disparity in learning comes from the inherent nature of groups that have both active and passive participants. Certain students often actively do the experimental portions while others passively participate. The goal of laboratory education, i.e., to give practical hands-on training to enhance conceptual understanding to every student remains compromised.

The purpose of this study was to investigate changing learning modalities of laboratory environments with focus on interventions to improve reflective thinking in skill education. The study aims at assessing reflective tendencies and encouraging them by integrating laboratory practical education with Virtual Laboratories (VLs).

2 Background

There are several theories characterizing the stages and processes involved in deep or transformative learning. Dewey's model (Dewey 1938) of interconnecting educative experiences to reflection, Kolb's model (Kolb 1984) of experiential learning, Schon's model of (Schön 1983) reflection as a practice, Gibb's model of cross-enrichment of theory and practice to enhance reflection (Gibbs 1988), Moon's model (Moon 2013) of provoking interpretations to complex ideas look into sequential set of events and learning. Another study (Bransford et al. 1999) categorizes teaching strategies as lecture-based, skill-based, inquiry-based, individual vs. group based and technology-enhanced learning. That study also listed three components contributing to reflective learning amongst students namely, metacognition, analogical reasoning and transfer of knowledge.

John Flavell (Flavell 1976) defined metacognition as "one's knowledge concerning one's own cognitive processes and products or anything related to them". Eggen & Kauchak (Eggen and Kauchak 1988) suggested the development of metacognitive skills was key to creating self-regulated learners. When considering student communities, metacognition was expected to impact many cognitive activities such as comprehension, communication, attention, memory and problem solving (Howard 2004).

Success of an individualistic learning process may be assessed by the extent of application in practical scenarios, often referred to as transfer of knowledge. Nonaka (Nonaka and Takeuchi 1995) suggested that knowledge creation and transfer happened through social or collaborative methods, as well as the individual's cognitive processes such as reflection. Transfer of knowledge assisted with engagement in tasks based on the knowledge gained from learning (Jun et al. 2010), (Chiou et al. 2010). Transfer of knowledge was assessed by analogical reasoning, a process of mapping a known source or analog to an unknown target. This mapping includes the process of identifying, matching and transferring the structural information (Vosniadou and Ortony 1989).

Computer-mediated learning tools have been used in STEM education to assist students with visualization of complex phenomena (Achuthan et al. 2015). Most knowledge imparted in classrooms was theory-oriented, while that gained in laboratories was skill and concept-oriented. Maximizing learning by enhancing understanding that results in better grasp of knowledge is quite challenging (Naghdipour and Emeagwali 2013). In this paper, we also consider the impact of virtual labs training on reflective learning in University classrooms.

2.1 Virtual laboratories

Similar to MOOCs as learning environments (Laplante 2013), emphasis on simultaneous development of laboratory oriented educational material has led to the development of virtual laboratories, allowing learners to understand and practice hands-on skills or protocols outside of the physical laboratory (Diwakar et al. 2012). ICT-enabled VLs allow self-controlled individualistic learning environments for students, which has been known to complement standard laboratory practices. The virtual labs used here were developed as an initiative of Government of India's Ministry of Human Resource Department under National Mission on Education through ICT, and were designed and developed to provide laboratory learning time and experience to university students, who do not have access to adequate laboratory facilities or equipment. In this paper, we used one of the 43 Virtual Laboratories (350 online experiments) in several disciplines (Raman et al. 2014) that were developed (see Fig. 1). These VLs were posed also as supplementary teaching tools with varied interactive multimedia content to emulate real laboratory experiences. With more than 230,000 registered online users, this platform has served to partly fill the large gap seen in laboratory education by providing learners with 24 × 7 access to a) simulation-based, b) animation-based and c) remotely triggerable

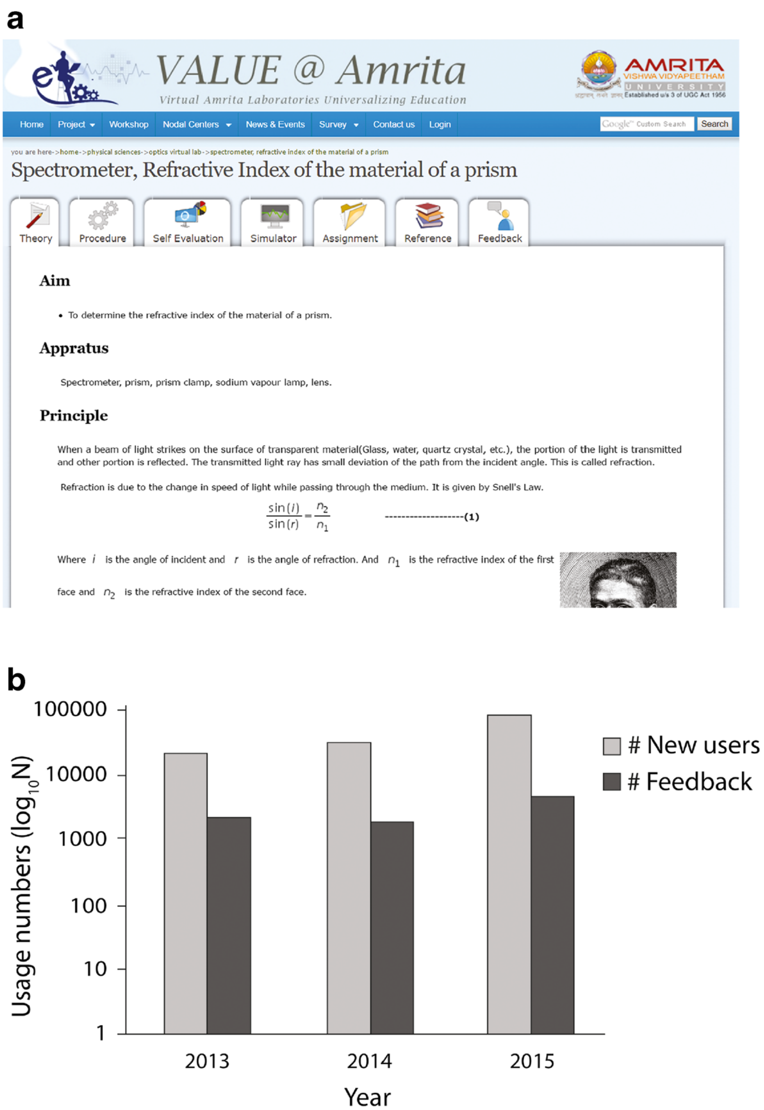


Fig. 1 ICT-based Virtual Laboratories used to test reflective learning and to augment laboratory skill training. A. Online experiments included theory, procedure, self-assessments, assignment, feedback in addition to simulation, animation and remote access tabs. Each virtual lab experiment was meant to be self-explanatory although they have been employed as interactive teaching material as well. B. Total usage of Virtual Laboratories. Online and blended usage numbers (log-scale on y-axis) across 2013–15 of Virtual Laboratory experiments. More than 350 experiments are hosted at http://vlab.amrita.edu

experimental interfaces to scientific concepts and instrumentation. In a physical lab, students work in groups, while in a virtual lab, students interacted with specific context-sensitive graphical elements developed to aid individual concept learning.

The VL platform has grown rapidly with millions of users around the world using them today. The virtual labs have been reported to have more than 230,000 registered users as of January 2, 2017, with a steady increase of new users since 2013 (see Fig. 1b). We saw two reasons for the adoption and usage of the Virtual Laboratories namely, availability of a single platform and usability as an Open Educational Resource (Raman et al. 2014). VLs have been perceived also as supplementary teaching tools with interactive multimedia content allowing an instructional preview to physical laboratory demos (Diwakar et al., 2014a, b, 2016).

3 Methods

Participants in this study were first year undergraduate engineering students, $N = 145$ (52 male, 93 female). About 74% of students were from computer science discipline and 26% of students were from the biosciences stream. These students were introduced to two types of experimental environments i.e. physics laboratory as well as the same technique via VLs. Students are categorized in to two groups: CPV ($N = 73$) students went through class room teaching (CT) then Physical Laboratory (PL) and finally performing Virtual Laboratory (VL); CVP ($N = 72$) students went through CT, VL then PL. A new assessment (see section 3.1) was conducted between the sessions (Fig. 2). Assessment data was collected after physical lab training as well as virtual lab training. Although data from 162 students was collected only 145 were considered for the assessment (some students were absent in one of the sessions and hence those data points were removed).

The physical laboratory and virtual lab experiment chosen for this study involved a spectrometer, a common experiment that all undergraduate students train on as part of their classroom theory as well as laboratory education. Learning objectives from this experiment involved not only the understanding of the concept of the experiment (access via http://vlab.amrita.edu/?sub=1&brch=281) in addition to the physical

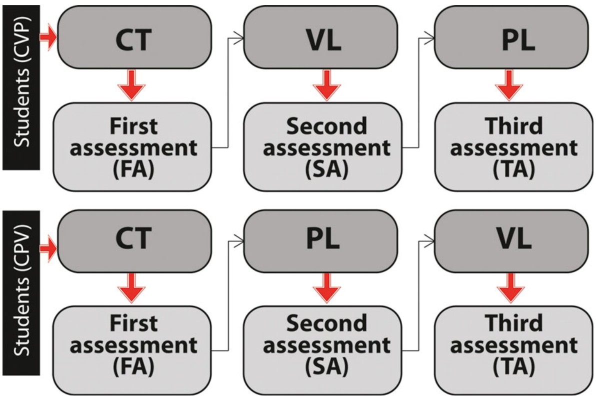


Fig. 2 Assessment models of MAT

operation of the instrumentation (see Fig. 3) involved in deriving the quantitative estimation of experimental measurements (Raman et al. 2011, 2014). All students who had used Virtual Laboratory (VL) and Physical laboratory (PL) learning environments were assessed on their understanding of concepts and its application.

Students spent approximately 2 h interacting and working on the online experiment. The interactive VLs had animations, simulations and videos, in addition to extensive theory and procedures They also included practice assignments and self-evaluation tests. An assessment was performed after the students attempted VL based learning. A retention study was also conducted by assessing the same students periodically over a 7-week period. We also conducted the retention study for a separate group of students, termed “class room training group” (CT), involving 45 student learners who did not use virtual or physical laboratories and were not a part of students used to test CVP and CPV test groups. Participants in CT group do not have access to physical or virtual laboratory but underwent classroom theory lessons using laboratory manuals as in traditional classroom courses. In our studies, since laboratory time was not included for CT group, they had one class hour less in the weekly routine compared to students in CPV and CVP groups. CT group was used as independent control group and as a reference to classroom teaching content only with lab skill education or practice.

3.1 Development of assessment method

Metacognition Metacognition has been defined as the process of developing self-awareness along with the ability to self-assess one’s learning (Flavell 1976). Having

Fig. 3 Physical and Virtual Lab training. **a** Student users in a physical laboratory. **b** Augmenting learning experience via Virtual labs post physical laboratory experience

metacognitive skills presumes that learners can set their learning goals, understand their learning styles and evaluate their own learning. Metacognition has been suggested to be used to assess factors assisting a student in gaining expertise (Sternberg 1998). The work involved the development of a questionnaire that assessed the metacognitive elements in learners to correlate reflective learning ability to the learning styles. In order to measure the metacognitive knowledge of students and effect of virtual lab on students self-awareness related to the laboratory knowledge, a questionnaire was made based on motivated strategies for learning (Pintrich et al. 1993), the metacognitive awareness inventory (Schraw and Dennison 1994) and awareness of independent learning inventory (Meijer et al. 2013). Questions related to metacognition included: whether the student learners had been introduced to a spectrometer earlier, what they felt about handling the equipment used in the experiment, concepts related to the device, theoretical principles of operation etc. It is to be noted that students may have different subject interests, i.e., some may have a larger affinity towards electronics in comparison to optics etc. This may also be attributed to their skill and therefore needed to be identified.

Analogical reasoning Analogical reasoning has been categorized as a process through which learners adapt their knowledge from a familiar scenario to an unfamiliar case (Vosniadou and Ortony 1989). Several studies on analogical reasoning have been done to measure the impact of innate analogical reasoning skills in learning (Abrantes 1999; Richland and McDonough 2010). The questionnaire assessed learners post laboratory process via computing specific parameters related to the experiment. Questions related to analogical reasoning in the current study included observations of parameters of the spectrometer, such as: calculation of angle of incidence, minimum deviation, refractive indices of materials or reading the Vernier scale etc.

Transfer of knowledge Transfer of knowledge was defined as when knowledge constructed in a contextual content was used in a different context, after being mobilized or recombined by the learner. This also depended on the extent of training one had to perform the task (Alipour et al. 2011). Transfer of knowledge using computer mediated learning tools provided not only technical challenges, but also many research opportunities (Jun et al. 2010). But, failures in transfer of knowledge have been known to occur when tasks were ‘over-embedded’ within the practice context (Detterman and Sternberg 1993). The transfer of knowledge questionnaire used in this study included application-oriented questions requiring descriptive type responses. Sample questions that related to the transfer of knowledge skills by students included: how easily they could translate what they read in the manuals to actual experimentation or if they could trace the path of light with different prism angles and refractive indices.

3.2 MAT instrument

The objective of MAT questionnaire was to assess underlying factors that contributed towards learning in laboratory environment. The questionnaire was developed integrating reflective metacognition and self-regulated learning (Ertmer and Newby 1996). An initial questionnaire taxonomy was developed and further refined into a 48-item list involving consultation with subject experts in physics with over 10 years of teaching experience. The list was administered to a set of students outside of the study and was evaluated for content, clarity and its alignment to the attributes. A reliability analysis was further conducted prior to this study (Creswell 2013). Cronbach's alpha of the MAT questionnaire that had the three observables was 0.85, making it a reliable instrument for identification of learning skills. The final questionnaire included questions on metacognition, analogical reasoning and transfer of knowledge.

The assessment of the three attributes was performed using a combination of Likert style questions (LS), multiple choice questions (MCQs) and True/False statements as well as descriptive questions. The questionnaire was administered in three formats: I – A questionnaire using a five-point Likert-type scale with anchors from "strongly disagree" to "strongly agree", II– An objective questionnaire that had a combination of multiple choice questions as well as True/False statements, III -a descriptive questionnaire.

Part I (30 questions) and Part II (10 questions) were completed by students in 30 min per section and were administered sequentially. An hour was given to the participants to solve Part III (8 questions) (also see Table 1). In Part I, about 70% of questions related to metacognition, 20% to analogical reasoning and 10% to transfer of knowledge. In Part II, all questions were structured as multiple choice questions and True/False statements. The MCQ style questions had 20% related to assessing metacognition, 40% analogical reasoning and remaining 40% related to transfer of knowledge. The True/False questions in Part II had 80% of questions related to metacognition and 20% related to analogical reasoning. The scores allotted for MCQ and True/False questions were one mark each. Part III had questions that were either descriptive short answer questions or were mathematical in nature for evaluating their ability to think analogically and transfer this knowledge in a problem-solving environment. The scores allotted for Part III questions varied between 4 and 20 marks. Scores were allotted based on number of concepts in the questions. In this section, 50% of questions related to analogical reasoning and 50% to transfer of knowledge.

Among three student groups CVP, CPV and CT, CVP and CPV were used to compare the learning roles during class room training, virtual laboratory training and physical laboratory training. CT group (45 students) was a classroom-only group without lab experience and was used for the retention study. MAT instrument was used to assess learning attributes (M, A and T) in CPV and CVP. As indicated, the MAT instrument contained three sections namely Likert style (LS), multiple choice (MCQ) and descriptive-type questions. Three assessments, first (FA), second (SA) and third (TA), using the same set of MAT questions were conducted after classroom training,

Table 1 Distribution of questionnaire for metacognition, Analogical reasoning and Transfer of knowledge

	Part I	Part II		Part III
Attribute	LS	MCQ	T/F	Descriptive
Metacognition	70%	20%	80%	-
Analogical Reasoning	20%	40%	20%	50%
Transfer of Knowledge	10%	40%	-	50%

LS – Likert Style questions, **MCQ** – Multiple Choice Questions, **T/F** – True/False virtual lab training and physical lab training on CVP and CPV groups. First assessment (FA) was conducted after class room-based teaching alone. SA with same questionnaire was performed for CPV after physical lab training and virtual lab training for CVP group was conducted. TA was performed after physical lab training for CVP and virtual lab training for CPV groups using the same questionnaire. Retention study was conducted every week over a 7-week duration using MCQ and descriptive type questionnaire in the MAT instrument. All three groups (CPV, CVP, CT) went through the retention study.

3.3 Designing the questionnaire for the assessment.

On the basis of the previous literature, we have developed domains for evaluating metacognition, analogical reasoning and transfer of knowledge. Each observable (i.e. M, A, T) was defined by four distinct domains and set of questions were prepared to access each of the domains that combine to say the effect of M, A and T. The domains for the metacognition was derived from the past studies of metacognition and its assessments, were categorized as 'Self-reported questionnaire based on subject domain' (Desoete et al. 2003; Kramarski and Mevarech 2003; Meijer et al. 2006; Veenman and Spaans 2005), 'Statements to support student's verbalized self-instructions'(Brown 1978) (Brown et al. 1981), 'Statements analyzing student's observations' (Jaafar et al. 2014; Pintrich and De Groot 1990; van Hout-Wolters 2000) and 'Statements to analyze stimulated recall with in the subject domain' (Afflerbach 2000; Veenman et al. 1993) (see Table 2). Self-reported questionnaire based on subject domain described types of questions to assess student's thoughts, beliefs and perceived knowledge about the topic.

Analogical reasoning was known to take place between two systems that belong to different domains, or between two systems that belong to the same or similar domains (Gentner and Toupin 1986). Inductive reasoning was considered to be an important element of thinking and learning that is particularly problematic for those with moderate and severe learning difficulties (Büchel et al. 1997). For assessing the analogical reasoning, the domains are 'remote conceptual domain' (Gentner and Toupin 1986), 'identifying surface similarity' (Vosniadou 1989), 'discovery of new knowledge'(Chen et al. 1997; Gentner and Toupin 1986; Goswami 2001; Hesse 1966; Waltz et al. 2000)., 'analogical mapping of domain' (Gentner 1983, 1986; Gentner and Landers 1985) (Table 3). Remote conceptual domain represented the analogy from near relation of the subject domain, and could connect the concept to the learner. For example, − "Refractive index of the prism is always greater than the refractive index of the surrounding". To answer this question, students need to resolve the solution by thinking analogically connecting the path of light travelling through the prism and the bending occurs due to the transmission of light from the prism to the surrounding. But this 'domain' does not have any direct relation to the aim of the experiment. The next 'domain' called 'identifying surface similarity' described analogical reasoning by comparing a schematic figure along with the questionnaire. 'Discovery of new knowledge' was a type of questionnaire which help to resolve the analogical reasoning question along with understanding of new perspective of learning. For example – "The edges of the prism have equal priority in the spectrometer experiment". With the help of a figure, student can identify the analogy of the two figure and understand new

Table 2 Sample questionnaire based on the four domains assessing metacognition

Component	Question	Reference
Self-reported questionnaire based on the domain of the subject.	• It is difficult for me to identify collimator and telescope of spectrometer apparatus.	(Meijer et al. 2013)
	• I am not concerned about the steps in performing the experiment with the apparatus.	
	• is easy for me to operate the spectrometer apparatus.	(Schraw and Dennison 1994)
	• The initial adjustments of the spectrometer apparatus is important before start of the experiment.	
	• I am familiar in handling the spectrometer apparatus.	
Statements to analyse student's verbalized self-instructions	• Preliminary adjustments are already set in the laboratory. I only need to place the prism and take the readings.	(Brown 1978; Veenman and Spaans 2005).
	• First step of this experiment is to focus the slit of the collimator using the telescope.	(Dunlosky and Bjork 2008).
	• One can freely rotate the collimator around the prism table in a spectrometer apparatus.	(Meijer et al. 2013)
	• Prism clamp is not necessary for doing this experiment.	
	• Prism has three faces.	(Vo et al. 2014).
	• There are three screws that are used to adjust the base of the spectrometer apparatus.	(Dunlosky and Bjork 2008).
Statements to analyse student's observations.	• Telescope in the spectrometer apparatus can rotate less than 360 degrees around the prism table	(Meijer et al. 2013)
	• I understand that the usual physical experimentation, prism angle sets 50 Degrees	(Martinez, Michael E 2006)
	• I have to tighten the holding screws of Telescope/Vernier, before starting the fine adjustment	
	• Refractive index of the prism is always greater than refractive index of the surrounding	(Dunlosky and Bjork 2008)
	• The angle between Vernier I and Vernier II is always 180 Degrees	
	• Emerged ray from the prism is used for finding the angle of prim	
Statements to analyse stimulated recall of the subject domain.	• Three edges of the prism have equal priority in the spectrometer experiment	(Meijer et al. 2013)
	• 10-min least count is common for all types of spectrometer apparatus	
	• Angle between reflected rays from the two faces of the prism, will be twice the prism angle	(Martinez, Michael E 2006)
	• It is possible to construct a prism which has the refractive index equal to the refractive index of surroundings	(Martinez, Michael E 2006)
	• Refractive index of the prism is inversely proportional to the angle of minimum deviation	

knowledge. The fourth domain called 'analogical mapping of domain' helped to assess the reasoning ability of the students with the help of the statement or a situation. This type of questionnaire was developed to motivate the students to think about the analogy in the procedure or situations and to create the connection with given statements.

Transfer of knowledge was a construct of enormous importance for both education and practice (Lauder et al. 1999). An individual perspective on knowledge and learning enables us to explore differences both in what and how people learn and in how they interpret what they learn. (Daniels et al. 2009). This transfer of knowledge was accomplished by mapping or matching processes which consist of finding the correspondences between the two systems (Gentner and Toupin 1986). Transfer of knowledge and skills has been described as the main goal of education (Prawat 1989), and as the ultimate goal of education for lifelong learning (Fogarty 1995). For the assessment of the transfer of knowledge we derived the domains from the basis of the previous literature, called 'access the ability to access one's intellectual resources' (Prawat 1989) (Renkl et al. 1996), 'mapping process to find the correspondences between two systems'(Lauder et al. 1999), 'access the ability to use certain procedures' (Lauder et al. 1999). An individual perspective on knowledge and learning enables us to explore differences both in what and how people learn and in how they interpret what they learn (Daniels et al. 2009) between the two systems (Gentner and Toupin 1986). Transfer of knowledge and skills has been described as the main goal of education (Prawat 1989), and as the goal of education in lifelong learning (Fogarty 1995). For the assessment of the transfer of knowledge, we derived the domains based on literature, called 'access the ability to access one's intellectual resources' (Prawat 1989), (Renkl et al. 1996), 'mapping process to find the correspondences between two systems' (Lauder et al. 1999), 'access the ability to use certain procedures' (Lauder et al. 1999). An individual perspective on knowledge and learning enables us to explore differences both in what

Table 3 Sample questions based on the domain for assessing analogical reasoning

Domain	Questionnaire	Reference
Remote conceptual domains	• Refractive index of the prism is always greater than refractive index of the surrounding • Angle between reflected rays from the two faces of the prism, will be twice the prism angle.	(Gentner and Toupin 1986).
Identify the surface similarity	• From the figure What are the parts of spectrometer apparatus? • Draw the schematic representation for the arrangement of minimum deviation of spectrometer. • What will be the difference between *vernier I* and *vernier II*?	(Vosniadou 1989).
Discovery of new knowledge	• The edges of the prism have equal priority in performing the spectrometer experiment (refer figure below). • In spectrometer apparatus, one student takes the emerged ray reading as $20^0 30'$ and direct ray reading as $330^0 30'$. What is the angle between these two readings?	(Gentner 1983; Gentner and Toupin 1986)
Analogical mapping of domain	• While doing the experiment, I do not care about where the edge of the prism is pointing. • Three edges of the prism have equal priority in the spectrometer experiment. • Function of collimator in spectrometer apparatus.	(Gentner 1986)

and how people learn and in how they interpret what they learn. (Daniels et al. 2009) (Gentner and Toupin 1986). Transfer of knowledge and skills has been described as the main goal of education (Prawat 1989), and as the objective of education for lifelong learning (Fogarty 1995). For the assessment of the transfer of knowledge, literature based assessment domains included, 'ability to access one's intellectual resources', 'mapping process to find the correspondences between two systems', 'access the ability to use certain procedures', 'subject knowledge and metacognitive domain' (Table 4). First domain describes the types of questions that can access the intellectual knowledge of the learner and apply to a scenario. The second domain assessed the ability to apply the known knowledge to identify the relation between two systems. Third domain interpreted one's ability to apply the learned procedure in a correct order. Fourth domain categorized to identify the subject knowledge and metacognitive ability by applying the knowledge to resolve subject related problems.

4 Results

An assessment of metacognition, analogical reasoning and transfer of knowledge of all students post classroom teaching was performed. A significant number of student scores were below 50%. Approximately 62% of students scored less than 50% in metacognition, while 69% scored less than 50% in analogical reasoning and 54% scored less than 50% in transfer of knowledge (see Fig. 4, Tables 5 and 6).

4.1 Impact of training on virtual and real laboratories

The students were split into two equal groups i.e. CPV and CVP (Figs. 2 and 3a, b). Three assessments of the three attributes were done to both groups. The first was after

Table 4 Sample questions for assessing transfer of knowledge

Domain	Questionnaire	Reference
Assess the ability to access one's intellectual resources	• It is difficult for me to identify collimator and telescope of spectrometer apparatus. • What is the least count of Spectrometer apparatus in your laboratory?	(Prawat 1989)
Mapping process to finding the correspondences between the two systems	• Refractive index of the prism is always greater than refractive index of the surrounding. • Refractive index of the prism is inversely proportional to the angle of minimum deviation.	(Gentner and Toupin 1986).
Assess the ability to use certain procedures	• Laboratory manual explains the initial adjustments of the apparatus. • There is no need to 'fine adjusting the screw' in spectrometer apparatus, while performing the experiment	(Lauder et al. 1999)
Subject knowledge and metacognitive domain	• What is the purpose of spectrometer apparatus? • A light travels from medium A to medium B. The angle of refraction is greater than the angle of incidence.	(Renkl et al. 1996; Halpern 1998)

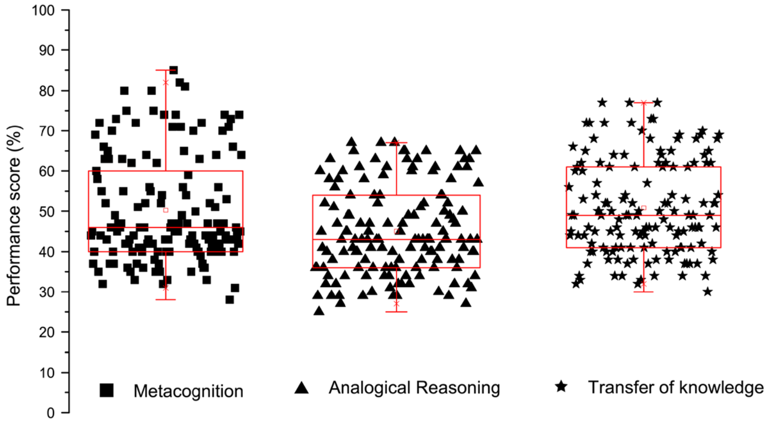


Fig. 4 Distribution of score of three observables (M-Metacognition, A- Analogical Reasoning, T- Transfer of Knowledge) in the first assessment (FA)

the classroom teaching, the second was done after the virtual labs for the C″V″P group and after physical labs for the C″P″V group. The third assessment was done after the physical lab for the CV”P″ group and after the virtual lab for the CP”V″ group (see Fig. 2). Post classroom training, the groups had similar average score and standard deviations (see Table 5). The combined mean scores of M, A and T were 47.71 and 48.95 for CPV and CVP groups. T-test shows t(144) = −0.69, $p > 0.05$ which represents there is no significant difference in groups based on the assessment of the attributes.

The students in CVP group underwent VL followed by real Labs (PL) while those in CPV were trained first on PL followed by VL. All three attributes were again assessed after both VL and PL in both groups.

4.2 Data analysis

Variation of score showed the effect of learning from physical laboratory and virtual laboratory. From the metacognition assessment (Tables 7, 10, 11), the gain in scores at the end of physical labs for the CPV group was 25% (Mean = 62.5) while at the end of virtual lab sessions for the CVP group were around 55% (Mean = 77.5). When both sets of groups underwent both physical and virtual labs, the overall increase in scores ranged between 70% (Mean = 84.7) to 83.3% (Mean = 92.2) for the CPV and CVP groups respectively. A sample t-test was conducted to study the variation in the score in-between each assessment for CPV and CVP groups (Table 7). Analysis showed

Table 5 T-test of CPV and CVP on first assessment (FA)

	Mean	SD	p	t
CPV	47.71	11.18	0.24	−0.69
CVP	48.95	11.12		

Table 6 Score distribution in MAT assessment

	Number of students, who scored in		
Category	Metacognition	Analogical reasoning	Transfer of knowledge
Below 50%	90	100	78
In between 50% and 75%	50	45	64
Above 75%	5	0	3

a significant difference in the scores when students underwent virtual labs training ($t(71) = -22.7$, $p < 0.05$) before handling physical labs ($t(72) = -12.0$, $p < 0.05$). The change was further perceived in the follow up assessments of CPV group that underwent one more round of learning from virtual labs after performing experiments in the physical lab. The mean score increased from 62.5 to 84.7 or a 35% increase in the CPV group in comparison to an incremental 19%. Mean score improved for students who did virtual labs before physical labs (Fig. 6). Another indication of the improved performance from virtual lab-based training was also seen as the higher slope observed for the CVP group in comparison to the CPV.

At the end of first assessment (after classroom teaching), the scores were similar with less than 3% difference between the CPV and CVP groups for analogical reasoning (see Fig. 5, Tables 8 9). However, the change between the groups in the second assessment when students were trained also on virtual labs was significantly higher with an increase 55% (mean score increases from 45.7 to 71.0) for CVP batch of students (see Table 8). The increase due to influence of training with physical labs in the CPV group after classroom teaching was approximately 22.57%, mean score changes from 44.3 to 54.3(see Tables 8 and 9). At the end of third assessment i.e. training on physical labs after virtual labs in the CVP group and training on virtual labs after physical labs in the CPV group, the scores converged to 84.6 (see Table 8). The results from p-value and t-test indicated significant changes in the second assessment after classroom teaching and with the third assessment (see Table 10). Also, CVP shows more significant differences ($t(71) = -23.31$, $p < 0.05$) in comparison to the CPV group ($t(72) = -17.4$, $p < 0.05$). Like metacognition (Table 7), in the case of analogical

Table 7 Comparing metacognition scores for first, second and third assessments

Group	Assessment	Mean	S.D.	p	t
CPV	FA	50.0	13.2		
	SA	62.5	12.2	0	−12.0
	TA	84.7	10.6	0	−16.6
CVP	FA	50.3	13.5		
	SA	77.5	9.5	0	−22.7
	TA	92.2	8.63	0	−16.9

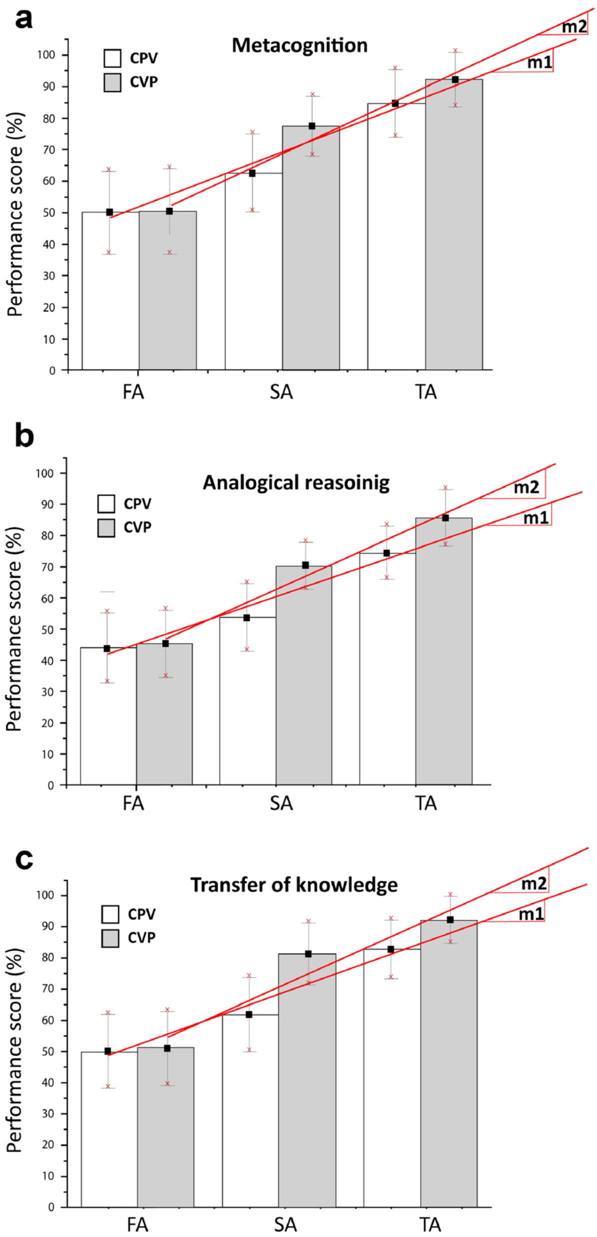


Fig. 5 Variation of score of CPV and CVP in three assessments of metacognition, analogical reasoning and transfer of knowledge. A. Metacognition for CPV vs CVP. The slope of the average score of CPV, m1 = 17.35 while the average score of CVP, m2 = 20.94. B. Analogical reasoning for CPV vs CVP. The slope of the average score of CPV, m1 = 15.54 while that of CVP, m2 = 20.39. C. Transfer of knowledge for CPV vs CVP. The slope of the average score of CPV, m1 = 16.33 while that of CVP, m2 = 20.55

reasoning assessments (Table 8), the slope reflecting the increase in scores across the three assessments indicating a steeper increase for the CVP group in comparison to CPV.

Table 8 Comparison of analogical reasoning scores for first, second and third assessments

Group	Assessment	Mean	S.D.	p	t
CPV	FA	44.3	11.2		
	SA	54.3	10.9	0	−17.4
	TA	84.7	8.5	0	−16.6
CVP	FA	45.7	10.9		
	SA	71.0	7.5	0	−23.3
	TA	84.6	7.4	0	−17.9

After classroom training, both groups CPV and CVP as in the case of prior attributes did not show significant differences for transfer of knowledge (see Fig. 5a, Table 11). In the CVP group with virtual labs after the classroom training, at the end of the second assessment a recognizable improvement in the scores of 58.67% (see Table 11), with mean scores changing from 51.3 to 81.4, was observed (see Fig. 5b, Table 9). In case of CPV group, at the end of second assessment the change in scores was around 23.50% (with mean scores increasing from 50.3 to 62.0). In the third assessment, there was a 33.70% change in the CPV group that had virtual labs training after physical labs. In the CVP group, however, the change in scores was about 13.14% (i.e. from 81.4 to 92.1). The statistical tests i.e. t-test and p-test showed that the increase in scores in the second assessment in the CVP group were higher ($t(71) = -23.7$, $p < 0.05$) in comparison to CPV group ($t(72) = -19.1$, $p < 0.05$). Final scores for both CPV and CVP groups varied between 82.9 to 92.1.

A common observation was that the significant variation to mean scores happened only when students underwent virtual lab training in both groups (see Table 10). In the CPV group, the steepest increase in mean scores were observed in the third assessment i.e. mean score increased from 58.8 to 80.9. The third assessment (see Fig. 5c) in CPV group was done after virtual lab session. In case of CVP group, the second assessment showed the highest increase in scores i.e. mean scores increased from 49.1 to 76.7.

One-way MANOVA revealed a significant multivariate main effect for region, Wilks' $\lambda = 0.261$, $F(9, 135) = 42.55$, $p < 0.001$, partial eta squared = 0.74. Power to

Table 9 Transfer of knowledge scores comparison for first, second and third assessments

Group	Assessment	Mean	S.D.	p	t
CPV	FA	50.2	11.8		
	SA	62.0	12.0	0	−19.1
	TA	82.9	9.4	0	−17.3
CVP	FA	51.3	11.8		
	SA	81.4	9.7	0	−23.7
	TA	92.1	7.3	0	−13.4

Table 10 Comparison of average scores for MAT assessments among groups

Group	Assessment	Mean	S.D.	p	t
CPV	FA	48.2	11.3		
	SA	58.8	10.4	0	−22.1
	TA	80.9	7.5	0	−22.3
CVP	FA	49.1	11.3		
	SA	76.7	7.1	0	−28.5
	TA	89.6	6.5	0	−22.7

detect the effect was 1 confirming significant differences between student groups, CVP and CPV. Percental univariate main effects for CPV and CVP groups were obtained for FA to TA (Table 10). First assessment (FA) indicated no significant change between two student groups CVP and CPV. Second and third assessments showed relative variations, F value indicated significant impact of virtual labs on student learners through a score improvement during second assessment (SA) and during third assessment (TA) after virtual and physical laboratory exercises (see Table 12).

4.3 Improvement in answering of questions

Independent analysis was conducted to estimate the change in the number of responses as a function in each assessment and types of questions. The types of questions included a combination of Likert style, multiple choice questions (MCQs) and True/False statements as well as descriptive questions show progression of the percentage of questions attempted by students in the first, second and third assessments by CPV and CVP groups respectively. For the CPV group, in the first assessment, approximately 23%, 42% and 60% attempted the descriptive questions, True/False and MCQ questions respectively (see Fig. 6a). In the second, the attempts increased between 60% - 70% at the end of physical lab while at the end of third assessments these numbers are between 93% - 100% (Fig. 6b). For the CVP group, in the first

Table 11 Percentage of score after second and third assessment

		Score improvement in %	
		CPV	CVP
SA	M	25.00	54.07
	A	22.57	55.36
	T	23.50	58.67
TA	M	35.52	18.96
	A	55.98	19.15
	T	33.70	13.14

Table 12 Tests of Between-CPV and CVP

Source	Dependent Variable		Mean Square	F	Sig.	Partial Eta Squared	Observed Power
Group	FA	M	3.75	.02	.88	.00	.05
		A	70.18	.56	.45	.00	.12
		T	39.43	.28	.59	.00	.08
	SA	M	8112.67	67.55	.00	.32	1.00
		A	10,208.24	115.87	.00	.45	1.00
		T	13,660.60	114.34	.00	.44	1.00
	TA	M	1999.27	21.50	.00	.13	.99
		A	3236.05	50.78	.00	.26	1.00
		T	3025.30	42.40	.00	.23	1.00

assessment, the questions attempted are 25%, 35% and 62% for descriptive, MCQ and True/False questions. In the second assessment, a raise to 79% - 89% was observed during evaluation after virtual lab practice and 100% was perceived at the end of third assessment (Fig. 6c).

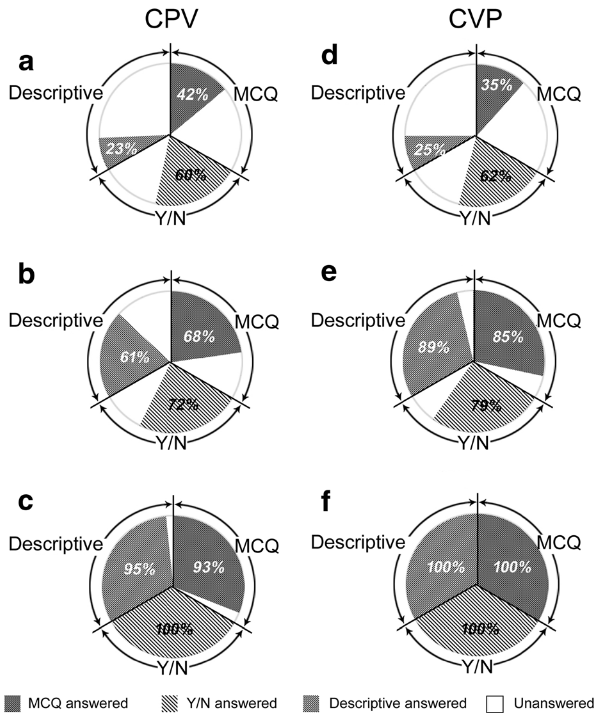


Fig. 6 Extent of questions answered by learners during CPV and CVP. **a**, **d** are scores during first assessment. **b**, **e** are scores during second assessment. **c**, **f** are scores during third assessment. See noticeable changes soon after second assessment with CVP where virtual lab training came after classroom training and before training with physical labs

4.4 Retention of gained knowledge

To verify if retention of gained skill knowledge was enhanced, all students were subjected to another set of periodic assessments. The assessments were conducted every week over a 7-week duration, using MCQ and descriptive type questionnaire. Students with VL training showed reliable retention of knowledge after several weeks of learning, demonstrated by negligible change in the scores over the period of assessment (Fig. 7). To compare the effect of VL, we used an independent group of students (not related to CVP and CPV) who had only undergone class room training (CT). We observed a rapid decline in scores among those that had classroom training only compared to CVP and CPV groups.

5 Discussion

Through usage and feedback analysis from other studies, virtual labs have already been observed to complement laboratory skill education by providing learners with 24 × 7 access to a) simulation-based, b) animation-based and c) remotely triggerable experimental interfaces to scientific concepts and instrumentation (Diwakar et al. 2016; S. Diwakar et al. 2014a, b; Radhamani et al. 2014; Sasidharakurup et al. 2015). In applying virtual labs as an educational tool, learner's proclivity to adapt the learning components was as relevant as transfer of knowledge, thereby allowing metacognition, analogical reasoning as components of the new assessments.

With student learners as CVP and CPV groups allowed us to understand roles of including virtual laboratories as pre or post-laboratory training exercise, where student

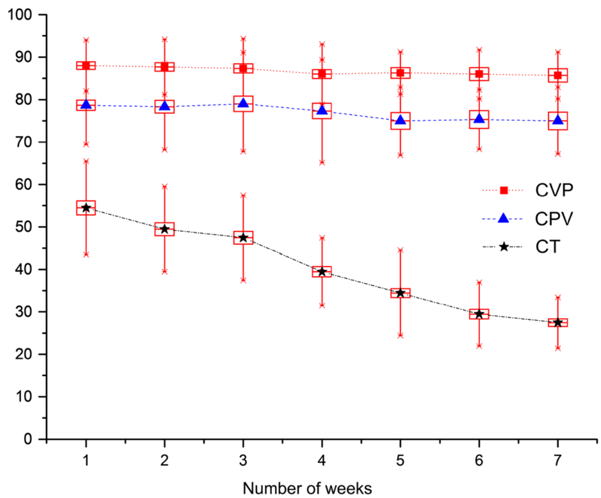


Fig. 7 Assessment of retention among CPV, CVP and class room teaching (CT) groups

groups who had virtual laboratory training showed more than 100% perceived understanding of concepts compared to those who only attended classroom lectures. The changes in the mean scores and slopes during MAT assessment also suggested that reflective learning was effective when virtual labs followed classroom training. A common observation with the MAT scoring was that the significant differences in scores happened when students had training with virtual labs in both groups. The use of virtual labs as a pre-laboratory or post-laboratory education platform may be used to help or identify learners with difficulties in understanding of concepts and applying the knowledge gained in newer scenarios.

With student's metacognitive level significantly increased after performing virtual laboratories, this study suggests the self-knowledge about a subject was enhanced. Teacher's metacognition on the topic also affected the overall performance of the students. In a classroom environment without ICT tools, teaching analogy in two different situations is not easy and time-consuming. Perhaps, this reflected on some students in their ability to interpret and solving the problems. Through animations and simulations, virtual lab helped students to augment analogical reasoning. Significant difference among groups in transfer of knowledge indicated, students with virtual lab training demonstrated better understanding about the subject and can use their training and perceived knowledge to solve problems. Virtual lab practice aided learners to improve the ability to apply knowledge in addition to providing basic concepts.

It may be essential to study student's proclivity in larger populations of subjects with different backgrounds as well across several subjects of study, to provide a more generalized understanding of how reflective learning was enhanced by using computerized emulations. We also noted that information retention in students improved with virtual laboratory training alongside physical laboratories during the 7-week tests. With the MAT domains as a reference, it may be proposed that VLs are effective and complementary ICT-based tools to support laboratory skill-training.

6 Conclusion

The focus of this study involving use of ICT-enabled virtual laboratories has been two-fold. An assessment based on three attributes, i.e., metacognition, analogical reasoning and transfer of knowledge (MAT) was developed to measure conceptual understanding of theoretical and practical concepts amongst students. The MAT assessment for reflective thinking was found effective in evaluating a significant sample of participants in a blended teaching environment. The second objective of the study was to enhance the reflective learning in classrooms using computer-mediated tools. Providing access to virtual labs before physical labs showed enhanced learning via MAT assessments. Retentivity studies may need more testing across longer time-scales but our initial study reveals virtual labs augment skill training and concept understanding complementing traditional classroom.

Acknowledgements Our work derives direction and ideas from the Chancellor of Amrita University, Sri Mata Amritanandamayi Devi. The authors would like to acknowledge the work of the entire CREATE team and the VALUE team for contribution and support for developing virtual labs. This work was supported by the Sakshat project of National Mission on Education through ICT, Department of Higher Education, Ministry of Human Resource Department, Government of India. SD was supported with Young Research Faculty Fellowship under Sir Visvesvaraya PhD scheme, Ministry of Electronics and IT, Government of India.

Appendix

MAT assessment questionnaire

Experiment: Spectrometer, prism

Assessment has 3 parts. Part 1- Likert-type questions, part 2- multiple choice questions and part 3- descriptive type questions (for assessing **M** - Metacognition , **T** – Transfer of knowledge and **A** – Analogical reasoning).

Part 1

Likert-type questions
1 = "strongly disagree"
2 = "disagree"
3 = "Neither agree nor disagree"
4 = "agree"
5 = "strongly agree"

1. I am familiar in handling the spectrometer apparatus.

   1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

2. I am not concerned about the steps in performing the experiment with the apparatus.

   1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

3. It is difficult for me to identify collimator and telescope of spectrometer apparatus.

   1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

4. It is easy for me to operate the spectrometer apparatus.

   1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

5. Preliminary adjustments have been already set in the laboratory. I only need to place the prism and take the readings.

   1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

6. Laboratory manual explains the initial adjustments of the apparatus.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

7. First step of this experiment is to focus the slit of the collimator using the telescope.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

8. The initial adjustments of the spectrometer apparatus are important before start of the experiment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

9. One can freely rotate the collimator around the prism table in a spectrometer apparatus.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

10. I understand the levelling of the prism table does not affect the setup.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

11. Prism clamp is not necessary for doing this experiment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

12. Three edges of the prism have equal priority in the spectrometer experiment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

13. Prism has three faces.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

14. It is possible to construct a prism which has the refractive index equal to the refractive index of surroundings.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

15. There are three screws that are used to adjust the base of the spectrometer apparatus.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

16. Telescope in the spectrometer apparatus can rotate less than 360 degrees around the prism table.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

17. Dark room is apt for conducting the experiment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

18. There is no need to do the initial adjustments, to start the experiment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

19. I understand that during the laboratory physical experimentation, prism angle sets 50 degrees.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

20. While doing the experiment, I do not care about where the edge of the prism is pointing.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

21. Emerged ray from the prism is used for finding the angle of prim.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

22. Refractive index of the prism is always greater than refractive index of the surrounding.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

23. There is no need to 'fine adjusting the screw' in spectrometer apparatus, while performing the experiment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

24. I perceive no difference if I perform the experiment in a dark room and an open space.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

25. I must tighten the holding screws of Telescope/Vernier, before starting the fine adjustment.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

26. Angle between reflected rays from the two faces of the prism, will be twice the prism angle.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

27. It is difficult for me to find the angle of minimum deviation in the physical laboratory.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

28. The angle between Vernier I and Vernier II scales is always 180 Degrees.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

29. 10-minute least count is common for all types of spectrometer apparatus.

1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

30. Refractive index of the prism is inversely proportional to the angle of minimum deviation.

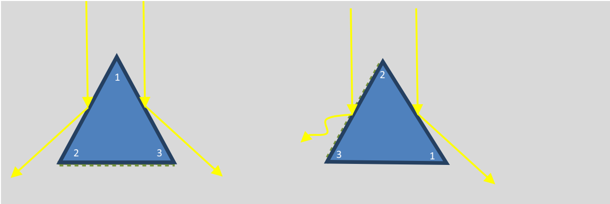
1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐

Part 2: **(1 mark each)**

1. What is the function of collimator in spectrometer?
   a) Produce parallel beam of light
   b) Produce converged beam of light
   c) Produce diverged beam of light
   d) Illuminate the prism.
2. A ray of the light travels from medium of refractive index, N_1 to a medium of refractive index N_2 , if angle of incidents is ‘i’ and angle of refraction is ‘r’ then sin(i)/sin(r) = ?
   a) N_1
   b) N_2
   c) N_2/N_1
   d) N_1/N_2
3. A ray of light incident at an angle of 20^0 is reflected back from a plane mirror, the angle between incident and reflected ray is?
   a) 40^0
   b) 20^0
   c) 60^0
   d) 50^0
4. Which material has the lowest refractive index from the given list?
   a) Glass
   b) Water
   c) Quartz
   d) Diamond
5. What is the least count of Spectrometer apparatus in your lab?
   a) 1’
   b) 1”
   c) 10’
   d) 10”
6. Angle of minimum deviation of glass prism is.
   a) $\approx 25^0$
   b) $\approx 37^0$
   c) $\approx 41^0$
   d) $\approx 45^0$
7. Refractive index of glass is
   a) 1.2
   b) 1.5
   c) 1.7
   d) 2
8. Suppose *Vernier I* is 100^0 30’, then, what will be the reading of *Vernier II?*
   a) $190^0$30’
   b) $280^0$30’
   c) $300^0$30’
   d) $200^0$30’
9. What will be the difference between *Vernier I* and *Vernier II*?
   a) 90^0
   b) 120^0
   c) 180^0
   d) 270^0
10. In spectrometer apparatus, one student takes the emerged ray reading as $20^0$30’ and direct ray reading as $330^0$30’. What is the angle between these two readings?
    a) 40^0
    b) 50^0
    c) 30^0
    d) 60^0

Part 3:

1. The edges of the prism have equal priority in performing the spectrometer experiment (refer figure below). (2 marks)



☐ Yes, because ……………………………………………………………………………………………………

☐ No, because ……………………………………………………………………………………………………

2. What is the purpose of spectrometer apparatus? (5 marks)

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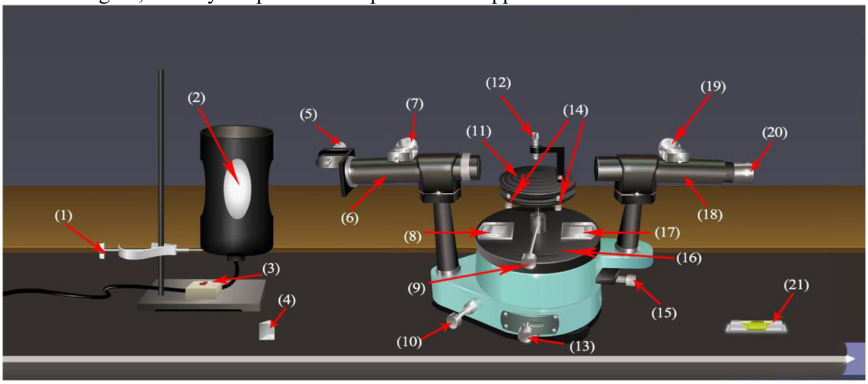
…………………………………………………………………………………………

3. From the figure, identify the parts of the spectrometer apparatus.

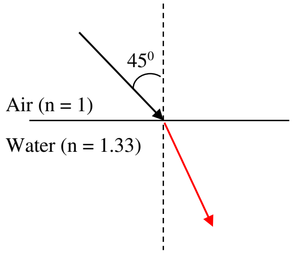


(1)……………………………………………(2)……………………………………………
(3)……………………………………………(4)……………………………………………
(5)……………………………………………(6)……………………………………………
(7)……………………………………………(8)……………………………………………
(9)……………………………………………(10)……………………………………………
(11)……………………………………………(12)……………………………………………
(13)……………………………………………(14)……………………………………………
(15)……………………………………………(16)……………………………………………
(17)……………………………………………(18)……………………………………………
(19)……………………………………………(20)……………………………………………
(21)…………………………………………… (21 marks)

4. Draw the schematic representation for the arrangement of minimum deviation of spectrometer. (5 marks)

5. Illustrate the figure which represents change in angle of refraction with respect to refractive index. (6 marks)

6. Calculate the angle of refraction and explain its law. (3 marks)
……………………………………………..
……………………………………………..
……………………………………………..



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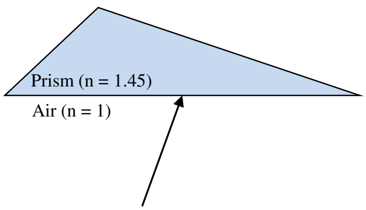
7. A ray of light is travelling through air towards a prism (n=1.45) in the shape of 50-100-30 triangle. Trace the path of ray of light through the prism. (4 marks)



8. A light travels from medium A to medium B. The angle of refraction is greater than the angle of incidence. (4 marks)
   a) Which medium has higher refractive index

   ………………………………………………………………………………………

   b) Which medium does the light travels at lower speed

   ………………………………………………………………………………………

References

Abrantes, P. (1999). Analogical reasoning and modeling in the sciences. *Foundations of Science, 4*, 237–270. doi:10.1023/A:1009623823171.

Achuthan, K., Brahmanandan, S., Bose, L. (2015). Cognitive load Management in Multimedia Enhanced Interactive Virtual Laboratories, in: El-Alfy, E.-S.M., Thampi, S.M., Takagi, H., Piramuthu, S., Hanne, T. (Eds.), Advances in intelligent informatics, advances in intelligent systems and computing. Springer international publishing, Cham, p. Pp 143-155. doi:10.1007/978-3-319-11218-3{_}15.

Afflerbach, P. (2000). Verbal reports and protocol analysis. *Handb. Read. Res., 3*, 163–179.

Alipour, F., Idris, K., & Karimi, R. (2011). Knowledge creation and transfer: Role of learning organization. *Int. J. Bus. Adm., 2*, 61–67. doi:10.5430/ijba.v2n3p61.

Bourne, J., Harris, D., & Mayadas, F. (2005). Online engineering education: Learning anywhere. *Anytime. J. Eng. Educ., 94*, 131–146. doi:10.1002/j.2168-9830.2005.tb00834.x.

Bransford, J.D., Brown, A.L., Cocking, R.R. (1999). How people learn: Brain, mind, experience, and school. Washington DC: National Academy Press.

Brown, A.L. (1978). Knowing when, where and, how to remember: A problem of metacognition. Metacognition. (Ed. Glaser) *Advances in Instructional Psychology, 1*, 225-253.

Brown, A. L., Campione, J. C., & Day, J. D. (1981). Learning to learn: On training students to learn from texts. *Educational Research, 10*, 14–21.

Bubnys, R., Žydžiūnaitė, V. 2010. Reflective learning models in the context of higher education: Concept analysis. Probl. Educ. 21st century (issues {…} 20, 58–70.

Büchel, F., Hessels-Schlatter, C., & Scharnhorst, U. (1997). Training and assessment of analogical reasoning in students with severe learning difficulties. *Educational and Child Psychology, 14*, 109–120.

Chen, Z., Sanchez, R. P., Campbell, T. (1997). From beyond to within their grasp: The rudiments of analogical problem solving in 10-and 13-month-olds. *Developmental Psychology, 33*, 790.

Chiou, H., Lee, Y., Purnomo, S.H. (2010). The influences transfer of training on relationship between knowledge characteristic of work design model and outcomes. *International Journal of Innovation, Management and Technology, 1*(2), 116–123.

Colomer, J., Pallisera, M., & Fullana, J. (2013). Reflective learning in higher education : A comparative analysis. *Procedia Social Behavioral Science, 93*, 364–370. doi:10.1016/j.sbspro.2013.09.204.

Creswell, J.W. (2013). Research design: Qualitative, quantitative, and mixed methods approaches. California: SAGE Publications.

Daniels, H., Lauder, H., Porter, J. (2009). Knowledge, values, and educational policy: A critical perspective. Abingdon: Routledge.

Desoete, A., Roeyers, H., & De Clercq, A. (2003). Can offline metacognition enhance mathematical problem solving? *Journal of Education & Psychology, 95*, 188.

Detterman, D.K., Sternberg, R.J. (1993). Transfer on trial: Intelligence, cognition, and instruction. Norwood: Ablex Publishing.

Dewey, J. (1938). Experience and education, The Kappa Delta Pi lecture series. London: Simon {&} Schuster.

Diwakar, S., Achuthan, K., Nedungadi, P., Nair, B. (2012). Biotechnology Virtual Labs: Facilitating Laboratory Access Anytime-Anywhere for Classroom Education, in: Agbo, E. (Ed.), *Innovations in Biotechnology* (pp. 379–398). Rijeka: Intechopen.

Diwakar, S., Parasuram, H., Medini, C., Raman, R., Nedungadi, P., Wiertelak, E., Srivastava, S., Achuthan, K., & Nair, B. (2014a). Complementing neurophysiology education for developing countries via cost-effective virtual labs: Case studies and classroom scenarios. *Journal of Undergraduate Neuroscience Education, 12*, A130–A139.

Diwakar, S., Radhamani, R., Sujatha, G., Sasidharakurup, H., Shekhar, A., Achuthan, K., Nedungadi, P., Raman, R., Nair, B. (2014b). Usage and diffusion of biotechnology virtual labs for enhancing university education in India's urban and rural areas. In *E-learning as a socio-cultural system: A multidimensional analysis* (pp. 63–83) Hershey: IGI Global.

Diwakar, S., Radhamani, R., Sasidharakurup, H., Kumar, D., Nizar, N., Achuthan, K., Nair, B. (2016). Assessing students and teachers experience on simulation and remote biotechnology virtual labs: A case study with a light microscopy experiment. Pp. 44–51. doi:10.1007/978-3-319-28883-3_6.

Dunlosky, J., & Bjork, R.A. (2008). The integrated nature of metamemory and memory. Handbook of memory and metamemory, pp.11–28.

Eggen, P. D., & Kauchak, D.P. (1988). Strategies for teachers: Teaching content and thinking skills/, 2nd ed. ed. Prentice-Hall, Englewood Cliffs

Ertmer, P. A., & Newby, T. J. (1996). The expert learner: Strategic, self-regulated, and reflective. *Instructional Science, 24*, 1–24. doi:10.1007/BF00156001.

Flavell, J. (1976). Metacognitive aspects of problem solving. *Nat. Intell., 12*, 231–235.

Fogarty, R. (1995). Best practices for the learner-centered classroom: A collection of articles. Arlington Heights: IRI/Skylight Training and Publishing, Inc.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science, 7*, 155–170.

Gentner, D. (1986). Structure-mapping in the development of metaphor. Unpubl. Manuscript, Univ. Illinois, Urbana.

Gentner, D., Landers, R. (1985). Analogical reminding: A good match is hard to find, in: Proceedings of the international conference on systems, man and cybernetics. Pp. 607–613.

Gentner, D., & Toupin, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science, 10*, 277–300. doi:10.1207/s15516709cog1003_2.

Gibbs, G. (1988). Learning by doing: A guide to teaching and learning methods. Manila: FEU.

Goswami, U. (2001). Analogical reasoning in children. *Analog Mind Perspect from Cognitive Science*, 437–470.

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. *The American Psychologist, 53*, 449.
Hesse, M. B. (1966). Models and analogies in science Notre. Notre Dame: University of Notre Dame Press.
Howard, J. (2004). Metacognitive inquiry. Sch. Educ. Elon Univ. http//Education-journal. htm 1, 2012.
Jaafar, S., Awaludin, N.S., Bakar, N.S. (2014). Motivational and self-regulated learning components of classroom academic performance. In E-proceeding of the Conference on Management and Muamalah 128-135.
Jacobs, G., & Murray, M. (2010). Developing critical understanding by teaching action research to undergraduate psychology students. *Educ Action Res, 18*, 319–335. doi:10.1080/09650792.2010.499789.
Jun, H. et al. (2010). Transferring Design Knowledge: Challenges and Opportunities. In X. Zhang et al., eds. Entertainment for Education - Digital Techniques and Systems. Proceedings of the 5th International Conference on E-learning and Games (Edutainment 2010). Berlin: Springer, pp. 165–172.
Kolb, D. (1984). Experiential education: Experience as the source of learning and development. Englewood Cliffs: Prentice Hall.
Kramarski, B., & Mevarech, Z. R. (2003). Enhancing mathematical reasoning in the classroom: The effects of cooperative learning and metacognitive training. *American Educational Research Journal, 40*, 281–310.
Laplante, P. A. (2013). Courses for the masses? *IT Professional, 15*, 57–59. doi:10.1109/MITP.2013.27.
Lauder, W., Reynolds, W., & Angus, N. (1999). Transfer of knowledge and skills: Some implications for nursing and nurse education. *Nurse Education Today, 19*, 480–487. doi:10.1054/nedt.1999.0338.
Manen, M. Van (1977). Linking ways of knowing with ways of being practical. Curric. Inq.
Martinez, M.E. (2006). What is metacognition?. Phi delta kappan, 87(9), 696-699.
Meijer, J., Veenman, M. V. J., & van Hout-Wolters, B. H. A. M. (2006). Metacognitive activities in text-studying and problem-solving: Development of a taxonomy. *Educational Research and Evaluation, 12*, 209–237.
Meijer, J., Sleegers, P., Elshout-Mohr, M., van Daalen-Kapteijns, M., Meeus, W., & Tempelaar, D. (2013). The development of a questionnaire on metacognition for students in higher education. *Educational Research, 55*, 31–52. doi:10.1080/00131881.2013.767024.
Mezirow, J. (1997). Transformative learning: Theory to practice. *New Directions for Adult and Continuing Education, 1997*, 5–12. Doi:10.1002/ace.7401
Michael, G. H., Voas, J., Miller, K., Laplante, P., & Bret. (2010). A nonlinear perspective on higher education. *Computer (Long. Beach. Calif)., 43*, 90–92. doi:10.1109/MC.2010.338.
Moon, J.A. (2013). Reflection in learning and professional development: Theory and practice. Routledge.
Naghdipour, B., & Emeagwali, O. L. (2013). Assessing the level of reflective thinking in ELT students. *Procedia - Social Behavioral Science, 83*, 266–271. doi:10.1016/j.sbspro.2013.06.052.
Nguyen, T. 2015. The effectiveness of online learning: Beyond no significant difference and future horizons. *MERLOT Journal of Online Learning and Teaching, 11*(2), 309-319.
Nonaka, I., Takeuchi, H. (1995). The knowledge-creating company: How Japanese companies create the dynamics of innovation. New York: Oxford University Press.
Peltier, J. W. (2006). Reflecting on reflection: Scale extension and a comparison of undergraduate business students in the United States and the United Kingdom. *Journal of Marketing Education, 28*, 5–16. doi:10.1177/0273475305279658.
Pintrich, P. R., & De Groot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Education & Psychology, 82*, 33.
Pintrich, P. R., Smith, D. A. F., Garcia, T., & Mckeachie, W. J. (1993). Reliability and predictive validity of the motivated strategies for learning questionnaire (Mslq). *Educational and Psychological Measurement, 53*, 801–813. doi:10.1177/0013164493053003024.
Prawat, R. S. (1989). Promoting access to knowledge, strategy, and disposition in students: A research synthesis. *Review of Educational Research, 59*, 1–41.
Radhamani, R., Sasidharakurup, H., Kumar, D., Nizar, N., Nair, B., Achuthan, K., Diwakar, S. (2014). Explicit interactions by users form a critical element in virtual labs aiding enhanced education – a case study from biotechnology virtual labs, in: 2014 I.E. sixth international conference on Technology for Education. IEEE, pp. 110–115. doi:10.1109/T4E.2014.37.
Raman, R., Achuthan, K., Nedungadi, P., Diwakar, S., & Bose, R. (2014). The VLAB OER experience: Modeling potential-adopter student acceptance. *IEEE Transactions on Education, 57*, 235–241. doi:10.1109/TE.2013.2294152.
Raman, R., Nedungadi, P., Achuthan, K., Diwakar, S. (2011). Integrating collaboration and accessibility for deploying virtual labs using VLCAP. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 2*(5), 547-560.
Renkl, A., Mandl, H., & Gruber, H. (1996). Inert knowledge: Analyses and remedies. *Educational Psychologist, 31*, 115–121.

Richland, L. E., & McDonough, I. M. (2010). Learning by analogy: Discriminating between potential analogs. *Contemporary Educational Psychology, 35*, 28–43. doi:10.1016/j.cedpsych.2009.09.001.
Rushton, D., & Lahlafi, A. (2013). Development, implementation and impact of active and reflective learning initiatives to improve web searching skills of international business students at Sheffield Hallam University. *UK. Procedia - Social Behavioral Science, 93*, 885–894. doi:10.1016/j.sbspro.2013.09.298.
Sasidharakurup, H., Radhamani, R., Kumar, D., Nizar, N., Achuthan, K., & Diwakar, S. (2015). Using virtual laboratories as interactive textbooks: studies on blended learning in biotechnology classrooms. *EAI Endorsed Trans. e-Learning*, 15. doi:10.4108/el.2.6.e4.
Schön, D.A. (1983). The reflective practitioner: How professionals think in action. New York: Basic Books.
Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology, 19*, 460–475. doi:10.1006/ceps.1994.1033.
Sternberg, R. J. (1998). Metacognition, abilities, and developing expertise: What makes an expert student? *Instructional Science, 26*, 127–140. doi:10.1023/A:1003096215103.
van Hout-Wolters, B. (2000). Assessing active self-directed learning. In: Simons, RJ., van der Linden, J., Duffy, T. (eds) *New Learning* (pp. 83–99). Dordrecht: Springer. Doi:10.1007/0-306-47614-2_5.
Veenman, M. V. J., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and Individual Differences, 15*(2), 159–176.
Veenman, M.V.J., Elshout, J.J., Groen, M.G.M. (1993). Thinking aloud: Does it affect regulatory processes in learning? *Tijdschrift voor Onderwijsresearch, 18*(6), 322-330.
Vo, V.A., Li, R., Kornell, N., Pouget, A., Cantlon, J.F., (2014). Young children bet on their numerical skills: metacognition in the numerical domain. *Psychological science, 25*(9), 1712-1721.
Vosniadou, S. (1989). Analogical reasoning as a mechanism in knowledge acqisition: A developmental perspective. In A. Vosniadou, Stella and Ortony, ed. Similarity and analogical reasoning. New York, NY, USA: Cambridge University Press, pp. 413–437.
Vosniadou, S., Ortony, A. (Eds.) (1989). Similarity and analogical reasoning. New York: Cambridge University Press.
Waltz, J. A., Lau, A., Grewal, S. K., & Holyoak, K. J. (2000). The role of working memory in analogical mapping. *Memory & Cognition, 28*, 1205–1212.