Cognitive Load Management in Multimedia Enhanced Interactive Virtual Laboratories

Krishnashree Achuthan, Sayoojyam Brahmanandan, and Lakshmi S. Bose

Abstract. Learning in multimedia enhanced interactive environments has distinctly impacted the cognitive processing of information. Theoretical learning requires conceptual understanding while experimental learning requires cognition of underlying phenomena in addition to a firm grasp of procedures and protocols. Virtual laboratories have been recently introduced to supplement laboratory education. In this paper, an outline of the modes of knowledge representation for virtual laboratories is presented. The results from this work show how the combination of physical and sensory representations in virtual laboratories plays a key role in the overall understanding of the content. Information processing through visual, auditory, pictorial as well as interactive modes offers unique pathways to cognition. An analysis of comprehension for N=60 students showed a significant change in the time taken to answer questions as well as an overall improvement in scores when exposed to multimedia enhanced interactive virtual laboratories (MEIVL). This study also portrayed a reduction in the perception of difficulty in understanding physics experiments. Statistical tests on various modes of assessments were done both online and in classroom quantify the extent of improvement in learning based on the enabling, facilitating and split attention aspects of MEIVL.

Keywords: cognitive load theory, multimedia, enabling, facilitating, split attention.

1 Introduction

A majority of today's youth undergoing higher education continue to learn in traditional settings with little exposure of revolutionary changes predominating the

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developed countries. One such revolution relates to ICT based learning techniques that has shown prominent impact in the educational system [1]. The integration of ICT into classrooms has improved pedagogic processes significantly [1]. What used to be a difficult and monotonous experience in teaching complex phenomena, has been completed overturned with the introduction of newer tools and techniques. Rote learning which is so prevalent in higher education and traditional classroom teaching has several limitations in delivering the concept to the students. In most cases the students learn only what is exposed to them by the teachers. ICT has facilitated the teachers to tap into the larger expanse of knowledge and empowered them to enhance their teaching methodologies.

Knowledge and comprehension are the fundamental metrics of learning. Application of this knowledge to real problems is the ultimate goal of higher education. Practical education is primarily offered in the form of laboratory sessions in the areas of sciences and engineering. Although the number of hours devoted to practical education is insufficient to expose them to diverse scientific problems, it is expected to provide real world experience. Due to limited lab hours, and inability to repetitively perform the experiments, the cognitive load on the students to learn the underlying phenomena is high within the stipulated time. Additionally, since most laboratory experiments are done in groups, the grasp of critical details by all students within the group can be subpar. One of the practical ways to address the cognition issues have been with enhancing teaching using visual media. Communication through words and pictures helps enrich learning technique [2]. The cognitive loads experienced by students as they are exposed to new information have been studied in detail by several researchers [3-4]. According to the cognitive theory of multimedia learning (CTML) human information systems includes dual channels for visual or pictorial and auditory or verbal processing and each channel has a limited capacity [2] of information adsorption. The use multimedia enhanced interactive virtual laboratory (MEIVL) has resulted in a new dimension to laboratory education [5]. There are various means of reducing the cognitive load during instructional design [3]. MEIVL provides visualization of concepts, and emphasizes enhancing skills by allowing repetition. This work relates to the characterization of MEIVL features and their impact of cognitive load.

2 Related Work

How we learn and process the information is described by the two essential components of human cognitive architecture, i.e., long term memory and working memory. The long term memory relates to information repository that can be exercised without conscious effort and the working memory relates to acquisition of knowledge [6]. The development of working memory includes learning skills that are learnt through human interaction without outstanding effort and those that have to be taught as in a classroom environment. The cognitive load theory (CLT) defines the influence and effective use of resources within the learning technique [7]. Cognitive load is most associated with design and development of instructional materials and their regulation or flow of information into the learner's memory

[3], [8]. Based on the different sources for cognitive load, Sweller et al [9] classified cognitive loads as intrinsic, extraneous or germane. Intrinsic cognitive load arises from the complexity of concepts requiring to be processed. Germane cognitive load, on the other hand, is determined by the degree of effort involved in processing the knowledge. Extraneous cognitive load is derived from the difficulties resulting from the instructional design. Both intrinsic and extraneous loads contribute to the total cognitive loads. Historically, education was imparted first orally which was followed by print media or text books. Pictures improved the cognition and became a regular feature of all learning material. It is impossible to imagine teaching science without the use of pictures and words. On the other hand, complex concepts which may be hard to explain through pictures and text can be taught with the integration of multimedia [6]. Thus visual presentation of any content forms the foundation of multimedia learning.

As mentioned by Mayer [2] dual code learning through sensory mode includes presenting information in multiple states i.e. static and dynamic content with pictures and words. Pictures can be static as well as dynamic. Static graphics includes illustrations and photos, while dynamic graphics includes animations or video. The CLT indicates that the sources of extraneous cognitive load such as split attention, redundancy and transiency should be reduced in multimedia based learning. The work on designing of online learning based on the cognitive load theory has been reported in the paper [10]. When Schar and Zimmerman [11] investigated means to reduce the cognitive load, they showed the presentation of content affected learning of dynamic concepts. They suggest presenting animated content in small chunks as an effective way to reduce the cognitive load. Finkelstein et al [12] in their comparative study between the students showed distinct differences in the influence of multimedia between groups that underwent educational training multimedia and far outnumbered in performance compared to those that did not.

This paper examines relatively unexplored educational innovation i.e. MEIVL from the cognitive load perspective. Some of key advantages of MEIVL are that it enables a learner to conceive invisible phenomena [13] and concepts. With interactivity integrated on individualized learning platform, MEIVL provides a plethora of possibilities in reducing the cognitive exertion required of students over time.

3 Multimedia Enhanced Interactive Virtual Labs (MEIVL)

The significant limitations of traditional laboratories for its inability to impart meaningful learning that allows substantial cognitive processing led to the development of MEIVLs. This was developed as part of a consortium where in over 1500 experiments in nine disciplines of engineering and sciences were designed for students pursuing higher education [5]. MEIVLs have a number of components such as description of the experiment, procedural listing of steps, videos exemplying the overall objectives and methods, a simulator with experimental parameters and an interactive animation. Although the comprehensive nature of MEIVLs make it an attractive supplement to theory and laboratory education, using multimedia for instruction can affect the cognitive load [1], [5]. Challenges in design of MEIVLs include understating if the cognitive processing required exceeds the learner's cognitive capacity. Fig 1 displays the modes of knowledge representation where in the relationship between various sensory elements to the MEIVL components are portrayed. The theory component of MEIVL includes words as well as pictures. Here pictorial representation of the concept behind the experiment given is in congruence with the text. Pictorial representations captivate the learners and grab their visual sensations. Simplicity of style in terms of presentation of the text assists with coherency.

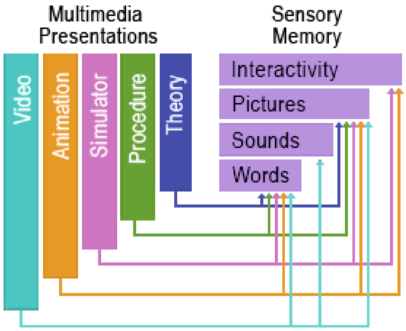

Fig. 1 Modes of Knowledge Representation in MEIVL

In the procedural component, each step for doing the experiment is systematically organized with static pictures. The simulator utilizes four memory factors, mainly focused on the appearance of the whole apparatus mimicking the real lab equipment. This is not only a visual representation but also interactive as the user can handle the apparatus virtually (e.g., adjusting knob). Instructions are given as words besides visual representations. The animations play instrumental role in expanding the imaginative thinking to perceive what may be invisible, and difficult to understand. Video aspects of MEIVL on the other hand does not interactivity, yet does utilize most sensory memory channels. Although all of these components for MEIVLs can be offered in a scalable fashion, the capacity to contain the information in the working memory can be very challenging. The next sections describe the characterization of the impact of components on cognitive load.

4 Methodology

In this study a sample of 60 undergraduate and graduate students pursuing their second year of engineering education were selected. Three experiments that were targeted for the study included measurement of refractive index by spectrometer, characterization of material property from Kundt's tube apparatus and gauging the thermal conductivity from Lee's disc experiment. These experiments were chosen based on the prior knowledge of the difficulty faced by most students in understanding the concept, procedure and significance of experiments. MEIVL components for the former two experiments included animations, theory, procedure, results and applications and the latter had them all except that it had a video instead of animation. The undergraduate students were divided into separate groups of 15 and were exposed to 1) traditional labs wherein the students performed the three experiments in groups or 2) MEIVLs that allowed individualized learning of the experiment on the computer. This was followed with different cognitive tests for perception and conceptual understanding.

4.1 Coefficient of Thermal Conductivity by Lee's Disc Experiment

Lee's Disc experiment computes the coefficient of thermal conductivity of a poor conductor such as glass, cardboard etc. The procedure involves placing the poor conductor, with certain dimension i.e. radius r and thickness x, between a steam chamber and two highly conductive identical metal discs. Once in equilibrium, the heat lost by the lower disc to convection is measured and equated to that flowing through the poor conductor. The upper disc temperature T_2 and the lower disc temperature T_1 are recorded. The poor conductor is removed and the lower metal disc is allowed to heat up to the upper disc temperature T_2. Finally, the steam chamber and upper disc are removed and replaced by a disc made of a good insulator. The metal disc is then allowed to cool through $T_1 < T_2$ and toward room temperature T_0. The temperature of the metal disc is recorded as it cools, so a cooling curve can be plotted. Then the slope $s1 = \Delta T/\Delta t$ of the cooling curve at temperature T_1 is recorded. This description, however still lacks step-wise procedure to perform experiment. But by looking at the simulator and video in MEIVL version of Lee's Disc experimental as shown in Fig 2, the learning outcomes can be significantly influenced.

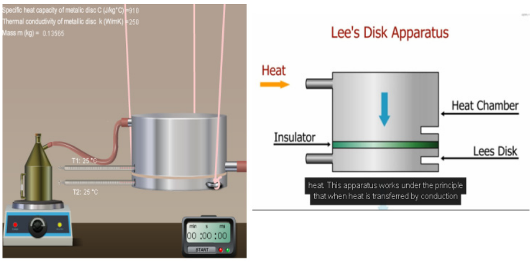

Fig. 2 Simulation and Video of Lees Disc Experiment

4.2 Refractive Index of a Prism

The aim of the experiment was to determine the refractive index and angle of a given prism. A detailed explanation of this experiment is given elsewhere [14]. In the MEIVL version, the visual representations like animation and simulation to explain how the light rays strikes on one surface and how the ray is transmitted and reflected through prism (Fig. 3).

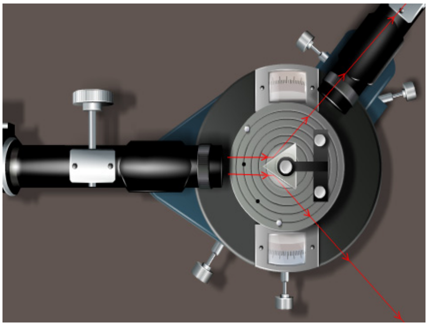

Fig. 3 Top View of MEIVL Spectrometer

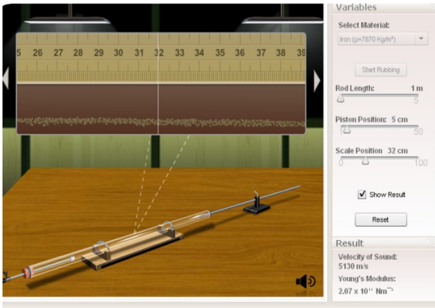

Fig. 4 Kundt's tube Apparatus Simulation

4.3 Sound Velocity and Young's Modulus of Materials

The objective of this experiment is to find the velocity of sound waves and the Young's modulus of the material of the rod. Knowing the speed of sound in air, the speed of sound v in a solid rod can be calculated based on the measurement of sound wavelength, λ. If the frequency of the sound wave, f is known, then the speed of sound can be calculated from v=fλ. The apparatus consists of a long transparent horizontal pipe, which contains a fine powder such as cork dust or talc. At the Simulator Screenshot Video Screenshot ends of the tube, there are metal fittings. At one end of the tube, a metallic rod, of uniform radius having one or two meter length is introduced. This rod is clamped at the middle and carries a circular disc, rigidly fixed at one end. The radius of the disc is slightly smaller than the radius of the glass tube. The rod is inserted inside the tube, without touching it, while its other end is plugged by a metallic piston. The position of the piston can be adjusted by moving it in or out. The whole apparatus is tightly clamped on a table, so that there are no jerks on the tube while performing experiment. The MEIVL version of this experiment displays instant changes with change in length of the rod.

5 Distinct Attributes of MEIVLs

This section describes a few of the distinct attributes of MEIVLs and their direct impact on the cognitive load.

5.1 Enabling Effect

The definition of an enabling effect of MEIVLs is that its features are fundamentally responsible in allowing students to understand specific concepts with clarity. As an example, Fig 5 shows a part of spectrometer called the telescope which is used to view image. For viewing the image we need to adjust the telescope for getting the clear image. So we tried to check whether the student will be able to understand the concept of how light rays travel through the telescope on moving the eye piece of telescope. In the traditional lab, it would be impossible to visualize these ray diagrams. By exposing students to MEIVLs, students were assessed on their understanding of correlation between the eyepiece movement and the flow of light

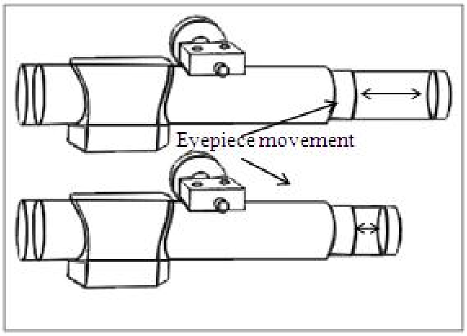

Fig. 5 Telescopic Positions and Eyepiece Movements

5.2 Facilitating Effect

Facilitating effect of MEIVLs demonstrate as how a task which was previously difficult to perform became far more effortless with the help of MEIVL. To exemplify, the procedural aspects of laboratory experiments are extremely critical to the successful performance of an experiment. Viewing and interacting with the animation and simulation respectively, the understanding of spectrometer adjustments that is done to determine the angle of prism was done by asking students to sort randomizing pictures (Fig 6) in the right order.

5.3 Split Attention Effect

Split attention effect enhances cognitive load by causing learner distraction from the exposed sources of information. This could result from lack of coherent organization of pictorial and textual content. This work investigated if split attention effect was induced by MEIVL. One of the examples that were used to measure this effect, based on Kundt's tube experiment is elaborated here. One set of students completed this experiment in traditional lab, while the other set using Eyepiece movement MEIVLs. Both sets of students were then asked to label the pictures shown in Fig 7 with a title based on their understanding.

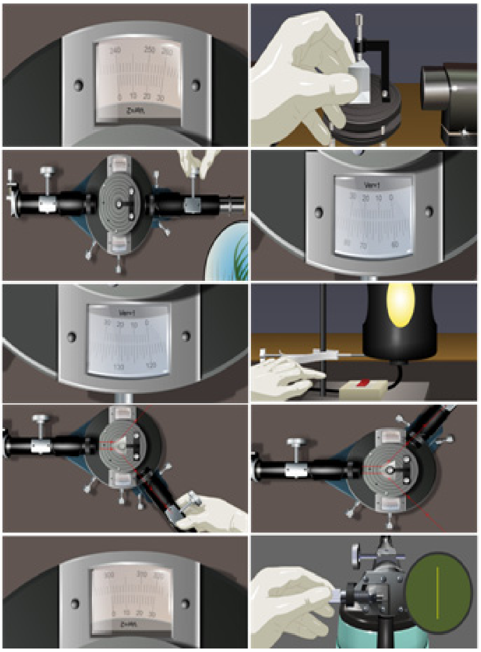

Fig. 6 Random Arrangement of Spectrometer Adjustments

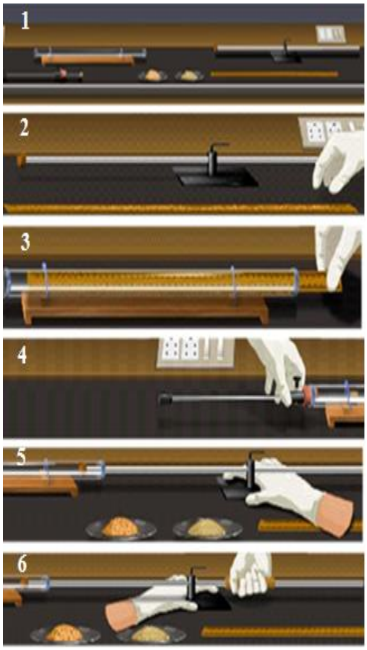

Fig. 7 Sequential Steps in Kundt's Tube Experiment

6 Results and Discussions

The students that were subjected to both traditional physical lab (PL) and MEIVLs were assessed for 1) their cognition of governing principles of three experiments detailed above 2) their understanding of procedural aspects of the experiments and 3) the speed of recollection. These assessments reflected the cognitive demand on the students from both approaches.

6.1 Difficulty Rating

Prior to analyzing the differences in the performance between the labs, the perception of difficulty amongst the students was first ascertained. Ten questions were given as part of a questionnaire. The questions given were of three types: 1) Theory - questions pertaining to theoretical aspects of physics phenomena that governed the experiments 2) Procedure – questions that only related the sequence of practical steps required to perform the experiments and 3) Application – questions that required understanding the concepts and applying them to solve problems. Fig 8a and 8b show the distribution of difficulty rating in these questions between the two sets of students that went through PL or MEIVL. The students that went through MEIVL found most questions in all three categories easier than those that went through PL. Another implication is that application oriented problems were twice as hard for the PL students than the MEIVL.

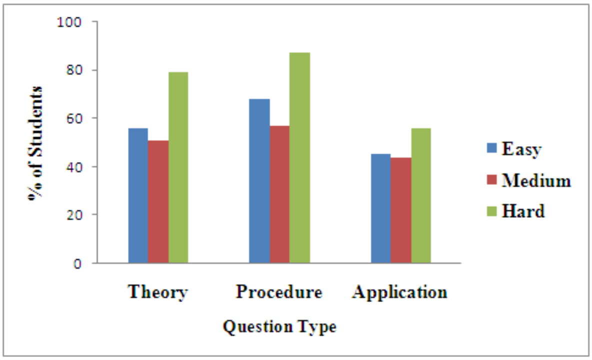

Fig. 8a Difficulty rating of Questions by MEIVL Students

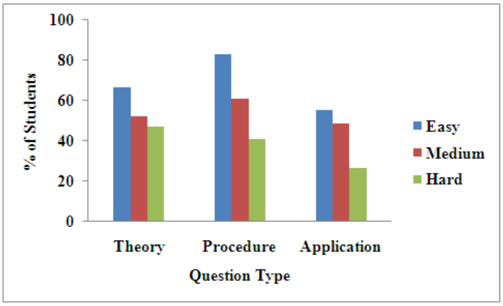

Fig. 8b Difficulty rating of Questions by PL Students

6.2 Speed of Recollection

An indirect measure of conceptual understanding is the speed of factual recollection. In this section, an online instrument that contained twenty questions that included multiple choice questions and pictorial ones were included. Students were divided into two groups those that underwent only PL and those that were exposed to MEIVL. A maximum time of three hours were given to answer the 20 questions or tasks. This being an online test, the time taken by individual students to complete the assessment was individually monitored. Fig 9 shows a plot of the percentage of students completing the task and the time taken to do the same. A significant advantage in terms of completion time is seen with MEIVL.

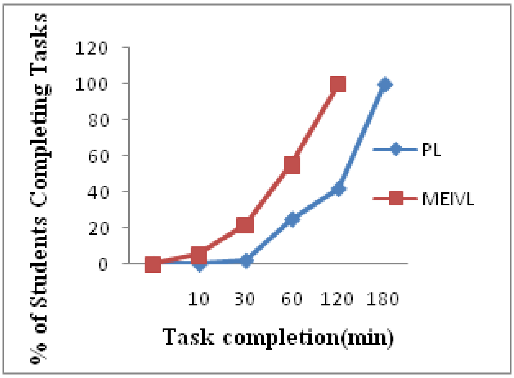

Fig. 9 Speed of Recollection

6.3 Cognition of Technical Content

Although there is significant improvement in the time taken by students to answer questions as seen in the previous section, it is more important to gauge their level of comprehension. Towards this, the scores from the assessed are plotted in Fig 10. Students that went through PL and MEIVL were first assessed and then compared to students that underwent both PL & MEIVL. The performance was monitored at the end of first hour and then again at the end of second hour. Three observations are made from this study. The PL students have poor understanding of the experiments average 20% scores while MEIVL demonstrate a much better performance averaging over 70%. Secondly extending the time for completion did not significantly help the students. Thirdly, subjecting students to both PL and MEIVL had similar performance as MEIVL alone.

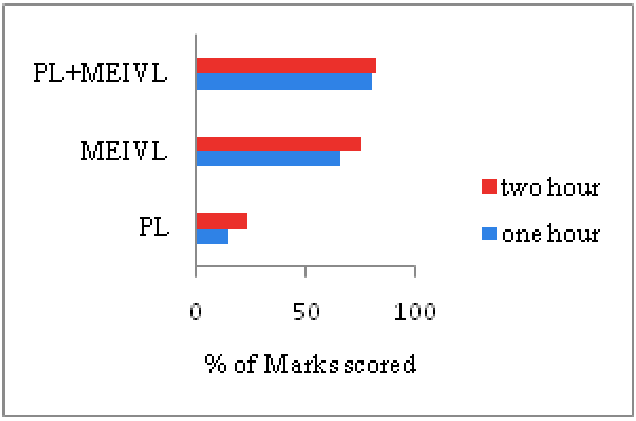

Fig. 10 Cognition of Technical Content

An independent t-test was conducted to examine the effect of MEIVL's attributes described in section 5. The results are tabulated in Table 1. To evaluate the enabling effect, the groups of students that went through MEIVL were able to easily identify the path of light rays through the telescope easily compared to those that did not. This is because unlike in MEIVL, the lab instructor in PL would not be able to show the movement of light rays. So it will be hard for a learner to conceive the idea of diagram without the help of MEIVL. When the facilitating effect of MEIVL was assessed on students by randomizing a sequence of procedural images, they had no issues in ordering them correctly. The challenge remained with students that were exposed to PL. The cognitive load in processing the information presented in the PL was too high and students performed poorly in spite of visual and textual information given to them. The split attention effects from MEIVL were also found to be low based on the high scores from this group. The PL group that was devoid of multimedia enhanced interactive features has to mentally integrate the picture with the text, a process that is cognitively demanding. In spite of the solution for the picture provided to them, the students found it hard to find a suitable answer by analysing the picture. So viewing the picture and there after reading the text or vice versa can imposes a load on the students. Taking an average of all students, the MEIVL group had a much higher mean score (N=15, M=18.52, SD=3.16) compared to the students that went through PL. (N=15, M=11.19, SD=3.09).

Table 1 Comparison of groups with and without animation in three different cases

Case	Group	N	Mean	SD	t Test
Enabling	MEIVL	15	4.86	1.03	t=2.048407
	PL	15	2.2	0.76	df=28, p=0.00000001106
Facilitating	MEIVL	15	5.13	0.83	t=2.048407
	PL	15	3.46	0.89	df=28, p=0.000013
Split Attention	MEIVL	15	8.53	1.30	t=2.048407
	PL	15	5.53	1.44	df=28, p=0.00000196

7 Conclusions

Laboratory education in most institutions is not given sufficient prominence and this in turn has resulted in scientists with poor laboratory skills. MEIVLs have brought in a much needed disruptive intervention in laboratory education practices. Based on the cognitive load theory and its influence on learning and adaptations to MEIVL, this work finds strong correlations to the quality of learning experiences and the cognitive load associated with it. From the various studies conducted MEIVLs have strong influences on the grasp of content due to the integrated visual, auditory, pictorial as well as interactive modes of engaging the students. Over 60% of students found the presentation, organization and delivery of MEIVL so effective in that the average mean score changed by over 50% on learning from MEIVL. The time to learn and present the learning in a coherent fashion is indicative of the enormous impact MEIVLs can have in the landscape of ICT based innovations. Irrespective of the type of assessment i.e. whether online or in the classroom, with limited or extended times, with type of questions asked in descriptive, definitional or multiple choice format, MEIVL group of students always did better by scoring 30% over the PL group of students. One of the reasons for such a large change in the performance is due to the reduction in the extent of difficulty that student faced in comprehending the phenomena with MEIVL. The cognitive loads can be greatly reduced with introduction of MEIVLs in mainstream laboratory education.

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