DESIGN OF AUGMENTED REALITY LEARNING SYSTEM AND
ANALYSIS OF ITS EFFECTIVENESS ON COGNITIVE LOAD
AND TECHNICAL SKILLS OF ENGINEERING STUDENTS

THESIS

Submitted

in fulfilment of the requirements of the

DOCTOR OF PHILOSOPHY

By

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DECLARATION BY THE STUDENT

I hereby certify that the work which is being presented in this thesis entitled “Design of Augmented Reality Learning System and Analysis of its Effectiveness on Cognitive Load and Technical Skills of Engineering Students” is for fulfilment of the requirement for the award of Degree of Doctor of Philosophy submitted in the Department of Electronics and Communication Engineering, Chitkara University, Punjab is an authentic record of my own work carried out under the supervision of Dr. Archana Mantri and Dr. Ojaswa Sharma.

The work has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgments have been made wherever the findings of others have been cited.

Gurjinder Singh
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<td>2D</td>
<td>2 Dimensional</td>
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<td>3D</td>
<td>3 Dimensional</td>
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<td>AR</td>
<td>Augmented Reality</td>
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<td>AREM</td>
<td>Augmented Reality Environment Modeling</td>
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<td>ARLE</td>
<td>Augmented Reality Learning Environment</td>
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<td>ARL</td>
<td>Augmented Remote Laboratory</td>
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<td>CAD</td>
<td>Computer Aided Design</td>
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<td>CLT</td>
<td>Cognitive Load Theory</td>
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<td>CSCL</td>
<td>Computer Supported Collaborative Learning</td>
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<td>DC</td>
<td>Direct Current</td>
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<td>DOF</td>
<td>Degrees of Freedom</td>
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<td>fMRI</td>
<td>Functional Magnetic Resonance Imaging</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>HMC</td>
<td>Head Mounted Camera</td>
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<td>HMD</td>
<td>Head Mounted Display</td>
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<td>ICT</td>
<td>Information and Communication Technologies</td>
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<tr>
<td>LCD</td>
<td>Liquid Crystal Display</td>
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<td>MR</td>
<td>Mixed Reality</td>
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<td>MRLE</td>
<td>Mixed Reality Learning Environment</td>
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<td>NFC</td>
<td>Near Field Communication</td>
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<td>PC</td>
<td>Personal Computer</td>
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<td>QR</td>
<td>Quick Response</td>
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<td>RFID</td>
<td>Radio Frequency Identification</td>
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<td>SDK</td>
<td>Software Development Kit</td>
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<td>TAM</td>
<td>Technology Acceptance Model</td>
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<td>TUI</td>
<td>Tangible User Interface</td>
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Augmented Reality is a technology which superimposes computer-generated virtual content on the physical objects in the computer-generated real scene. The technology can influence the user experience in dealing with real physical objects. It utilizes computer hardware for computing and visualizing the virtual content in the real scene. Augmented Reality has a wide range of applications in the field of automotive, architecture design, medical, education, and military applications. In the education sector, Augmented Reality has a great prospect due to its visualization capabilities. Augmented Reality has been used extensively for demonstrating the different scenarios, difficult concepts, and theories to the students which they can see in normally. In engineering education, laboratories are of great importance as they provide practical exposure to the students. But there are certain challenges which students and teachers face during the course of action. The following are the challenges which were faced during the laboratory courses: The cost of procuring the expensive laboratory equipment; The time constraint of students for availing laboratory facilities, as laboratory was utilized in other courses also; The risk of damaging the equipment when operating it without the instructor support; The student face problems in operating the complex laboratory equipment due to lack of expertise and time. These challenges encourage to utilize Augmented Reality technology for simplifying the learning process in engineering laboratories. In this study, Augmented Reality technology was utilized to
develop a learning system for electronics engineering laboratory. In electronics engineering laboratories, function generator and oscilloscope are the commonly used laboratory equipment. To operate this equipment, the student needs practice and expertise so an Augmented Reality-based learning system was developed to give prior training to the students before operating this equipment. The Augmented Reality learning system was developed on the learner-centered approach which engages the learner and completely involve in the learning process.

The exploratory research aims to determine the impact of Augmented Reality intervention on the student technical skills and cognitive load. The experiment was conducted in the two phases in the electronics engineering laboratory. In phase 1, sixty engineering students participated in the research. The participants were divided randomly into two groups: treatment group (N=30) and control group (N=30). The participants of the treatment group were taught with Augmented Reality learning system and the participants from the control group were treated with traditional teaching methodologies. To measure the student technical skills in laboratories, a laboratory skill test was designed by the teachers. To measure the cognitive load of students, cognitive load questionnaire was utilized which is based on the parameters defined in cognitive load theory. The experimental results suggest that Augmented Reality intervention has a significant positive impact on student technical skills and cognitive load. In phase 2 of research, the impact of changes in the design framework of Augmented Reality learning system was measured on technical skills and cognitive load of students. The design
framework of Augmented Reality learning system was modified as per the feedback received from the students. The experimental results suggest that there is a significant improvement in the laboratory skills of the students when design framework of Augmented Reality learning system was modified but there is no significant impact on the cognitive load of the students.

In this exploratory research, AR learning system was used along with real laboratory hardware to provide learners with the novel learning experience. The AR learning system was used as teaching aid on which students were given prior training about the laboratory hardware and after that they were exposed to the real laboratory equipment. The blended learning approach of combining real hardware along with virtual learning experience is the best way to achieve the learning objectives. The findings of the research suggest AR as an appropriate technology for engineering education, universities and educational institutions should assist educators in creating distinctive AR environments for learners to improve the quality of education.
Chapter 1
Introduction

1.1 Introduction to Augmented Reality

According to Azuma, Augmented Reality (AR) is a variant of Virtual Reality. In virtual reality, the user is completely submerged in virtual environment and linked with the virtual components (Azuma, 1997). While in AR, a consolidated illustration of computer produced virtual components and the client’s actual scene is created. To conserve the experience of real physical world, AR arrangement blends the virtual parts with a perspective of the real world scene to generate combined display. AR is an innovation in which computer-generated virtual substance communicate with genuine physical things.

According to Milgram’s Virtual-Reality (VR) Continuum, real environment and virtual environment are at the two opposite ends, AR lies in between them as shown in Fig. 1.1 (Milgram, Takemura, Utsumi, & Kishino, 1995). The real environment comprises of real things and the user can observe real-world scene whereas the virtual environment comprises of virtual components and computer-generated graphics. In the AR scene, virtual graphics augments the real environment with supplementary information.

![Mixed Reality (MR)](image)

Fig. 1.1 Milgram’s Virtual-Reality Continuum
1.2 Key Essentials of AR System

In order to develop an AR system, there are six key essential areas that are vital to develop the application (Feng Zhou, Duh, & Billinghurst, 2008).

- **Graphics Rendering:** Graphics rendering refers to design of the virtual content for AR learning environments. In graphics rendering, 2D-3D models of physical objects are designed with the help of specialized software tools like Autodesk Maya, Blender, Autodesk 3ds Max, SolidWorks etc. The quality of virtual graphics will enhance the user experience and interaction.

- **Tracking techniques:** Tracking techniques play a very important role in AR system as it used to calculate the position and orientation of the physical target present in the real environment on which virtual component can be successfully overlaid. AR system further utilizes the position and orientation coordinates for successfully superimposing the virtual graphics on to the physical object (Singh & Mantri, 2015).

- **Calibration & Registration:** Calibration is the process to precisely align the views of the real environment and virtual environment and to successfully overlay the virtual objects within the physical environment is known as registration. After successfully tracking the position and orientation of real objects, virtual objects are registered in the real environment which collectively offers the AR view to the user.

- **Display techniques:** It enables the user to visualize the actual world along with virtual objects overlaid on it. Display devices like VR headgear, mobile phones, tablets, PC screens can be used as display devices.

- **Processing Hardware:** High-performance computer processing hardware is required to execute the AR simulation code as virtual graphics require high computing power to render the graphics.

- **User Interfaces:** It allows the user to operate the AR virtual content and interacts with the AR system. Interaction devices like touch screen, leap motion
controllers, Kinect devices, cameras are used to take input from the user and accordingly it performs tasks and activities on the virtual objects.

1.3 Tracking Techniques for AR

Tracking technique is one of the important aspects of AR applications. Tracking technique allow the AR system to track physical target available in the real environment. Tracking techniques help in determining the position and direction coordinates of the physical target in the real environment. Further, AR software uses the position and direction data for superimposing the virtual components in the AR scene. The effectiveness of the tracking technique is judged on two parameters: High accuracy and low jitter (Feng Zhou et al., 2008).

Tracking techniques are broadly divided into three categories: sensor tracking, vision tracking and hybrid tracking. Fig. 1.2 presents the different tracking techniques available for AR applications.

![Tracking Techniques Diagram](image)

Fig. 1.2 Types of Tracking techniques for AR applications

According to (Cheng & Tsai, 2013), AR works on two types of techniques: Image-based AR and Location-based AR. Image-based AR uses computer vision techniques to track physical markers such as paper markers and QR codes. The webcam or mobile camera is used to track these physical markers and then AR software will augment the virtual graphics on them. Whereas location-based AR
uses GPS and other navigational sensors which helps in tracking the position and orientation of the target object (Barak & Asakle, 2018).

1.3.1 Sensor-based Tracking

Sensor-based tracking methods employ different non-camera-based sensors such as magnetic sensors, ultrasonic sensors, inertial sensors, RFID, GPS, mechanical sensors or acoustic sensors to track physical items in the real surroundings. The benefit of using such sensors is that they have a high rate of updates however all the while they are inclined to ecological or encompassing noises (Chan, Leung, Tang, & Komura, 2011; Singh & Mantri, 2015).

1.3.2 Vision-based Tracking

Vision-based tracking techniques are mainly based on computer vision and image processing techniques. Vision-based methods utilize one or more than one camera for tracking and successive frames were examined to calculate spatial association among them. Vision-based methods are mainly closed loop system which reduce error. Vision-based tracking techniques are further divided into two categories: Marker-based tracking and feature-based tracking.

1.3.2.1 Marker-based Tracking

The marker-based vision tracking techniques is the most general and widespread used techniques in earlier days. A marker is an image or a unique sign that AR system can identify using computer vision or image processing techniques. Marker-based technique increases robustness and reduces computational necessity but the utilization of markers need a definite upkeep (Naimark & Foxlin, 2005). Marker based technique is widely used in AR applications. There are many types of markers which are utilized in AR like image markers, sign markers, QR codes, circular markers etc. as shown in Fig. 1.3.
The marker-based tracking technique involves the following steps to detect the marker:

- Image acquisition and pre-processing
- Marker identification and decoding
- Pose calculation

In the first step, image of marker is acquired with the help of camera. After acquiring the image, there is a need to pre-process the image. In pre-processing, the acquired image is converted into greyscale image. In next stage, marker identification is done. In marker-identification, the corners and boundary of greyscale image is identified by using computer-vision techniques. The low level computer-vision techniques like edge detection, thresholding are used for identifying markers. The last stage of marker-based tracking is pose calculation. In pose calculation, the position and orientation of object is calculated in three-coordinate system. The location of marker can be expressed by translation coordinates \((x, y, z)\) and orientation can be stated by rotational angles \((\alpha, \beta, \gamma)\). Thus pose of object has 6 degrees of freedom (DOF). A framework can calculate the marker posture relative to the camera in 3D coordinates utilizing the four corners of the marker (Taehee Lee & Hollerer, 2009). The main purpose of tracking is to successfully and accurately overlay the virtual content in real environment as if they are present in real environment. The camera pose estimation is very crucial in rendering the virtual content in real scene.
1.3.2.2 Feature-based Tracking

Feature-based tracking is a type of vision-based tracking which utilizes the features of the real object for tracking. It is also known as tracking without paper markers. It works in the same way as marker-based tracking works but it requires complex computer-vision algorithms to identify the features of objects present in real environment. The features like edges, colors, shapes are used for tracking. Feature-based tracking is more robust and ubiquitous when compared with marker-based tracking as it doesn’t require to mount artificial markers in the real environment (Taehee Lee & Hollerer, 2009). Feature-based tracking is further categorized into two categories: Natural-feature based tracking and Model-based tracking.

Natural-feature based tracking uses natural markers available in the environment for tracking purposes. The main challenge with natural feature tracking is to find exclusive natural markers in environment as it involves a huge struggle to identify unique markers in the real environment.

Model-based tracking methods utilizes the models based on the highlighted structures of physical objects, for example, CAD models. Model-based trackers make their model dependent on the lines or edges accessible in the model. Model-based method uses existing articles or items in the environment as markers (Fischer, Eichler, Bartz, & Straßer, 2007). The model-based method has reasonably more range than the marker-based technique, however, the complexity and computational requirement are increased considerably.

1.3.3 Hybrid Tracking

Vision-based tracking alone can’t give resilient tracking and pervasive computing to AR applications. Hybrid tracking framework depends upon both sensor-based and vision-based methods. Hybrid tracking alludes to utilize combination of numerous sensors alongside computer-vision approaches and frame a sensor network for strong and pervasive computing. In the event that any of the sensor will fall short, the data can be extricated from the other sensors. Compared to vision-based tracking, hybrid tracking is more promising as it is a combination
of vision-based and sensor-based tracking. The combination of countless sensors will enhance general accuracy and robustness of monitoring.

1.4 Display technologies in AR

According to Milgram, AR display technology is of two types: See-through AR displays and Monitor-based AR displays. See-through AR display allows the user to directly see through the display medium which brings more realism of presence in the real environment. It generally uses head-mounted devices for display and provides an immersive experience to the user. Whereas monitor-based AR display uses computer and mobile screens to display the AR content to the user (Milgram et al., 1995). With the enormous growth of information and communication technologies (ICT) nowadays, personal computers, tablets and mobile devices has great processing and computational capabilities. Due to the mobility and low cost of personal computers and mobile devices, they are more apt display technologies for education sector. See-through AR displays are more preferred in the areas like military training and medical.

Fig. 1.4 Optical See-through AR (Broll et al., 2004)
1.5 Impact of AR Technology in Education

Prior studies have proved that technology can improve learning and teaching practices. AR has a positive influence on the learner experience as it augments virtual data in the real scene (Y. Chen, 2013; M.-B. Ibáñez & Delgado-Kloos, 2018). Traditional teaching approaches are all about books and 2D images whereas AR adds 3D experience to the learning, the learner can visualize the complex theories and phenomenon in 3D which enhances the understanding and knowledge retention. AR has a wide-ranging application in the field of entertainment, medical, military, training and education. In the education sector, AR has tremendous potential and exceptional pedagogical value that offers unique approaches for education. The technological design of AR can support instructional design to improve the learner experience (Akçayır & Akçayır, 2017; Goff, Mulvey, Irvin, & Hartstone-Rose, 2018). AR technology can reduce the mental effort of the learner in understanding and memorizing the concepts as the contents learned with AR approach is more strongly remembered when analyzed with non-AR methods of instruction (Drljevic, Wong, & Boticki, 2017; Radu, 2012). AR has the ability to enhance the visualization of students, AR is very effective where a student can’t
visualize the process like chemical reactions, nuclear reactors, machine internal operation etc. (Bower, Howe, McCredie, Robinson, & Grover, 2014; Di Serio, Ibáñez, & Kloos, 2013; Hua, Fang, Li, Yu, & Li, 2008; Kilani, Torabi, & Mao, 2018; Küçük, Kapakin, & Göktaş, 2016; H.-C. K. Lin, Chen, & Chang, 2015; Rojas-Sola & Aguilera-García, 2018). With the help of AR technology, the teaching and learning process can be eased down to understand the difficult processes.

The education practices are improving due to the advancement in information technologies (Dündar & Akçayır, 2014). The rapid growth and development of mobile technology enable learners to have a better understanding of AR. Modern smartphone is a package of powerful processors, cameras, touchscreens, GPS, accelerometers, compass etc. which adds more flexibility, robustness, and reliability to AR applications (Broll et al., 2008; Liu & Chu, 2008). Also, the mobility of mobile devices allows learners to have better physical experience anytime and anywhere (Carolyn Yang & Chang, 2013).

Conventional education methodology is evolving into a smart education system using smart devices and digital learning platforms (Abbasi, Hussain, Arafat, Lytras, & Aljohani, 2018; Aeiad & Meziane, 2019; Echeverría et al., 2012; Valdez, Ferreira, Martins, & Barbosa, 2015). AR technology is also emerging as a great prospect in education. AR has the capability to bring more interactivity during learning which raises attention, motivation, excitement in learning and enhances the learning experience of students (K.-E. Chang et al., 2014; Dunleavy, Dede, & Mitchell, 2009; Slijepcovic, 2013; Sommerauer & Müller, 2014). AR applications have the advantage of portability and can be used by multiple users at the same time (El Sayed, Zayed, & Sharawy, 2011). This provides the opportunity for collaborative learning in areas like science education, engineering education, architecture design, and mathematics etc.

1.6 Cognitive Load

The complete mental effort necessary to place during the assignment in the working memory is known as cognitive load. Cognitive Load Theory (CLT) divided the cognitive load into three classifications: Intrinsic, Extraneous and Germane. Intrinsic cognitive load is the cumulative effort connected with the topic's
complexity. The complexity of the topic cannot be altered so intrinsic cognition is constant for a particular topic. Whereas extraneous cognition is associated with the instructional design and depends on the method by which material is being offered to the student. Germane cognition was defined as the collective effort required to create an everlasting pool of knowledge (Sweller, 1994). The overall sum of cognitive load for a specific individual beneath a specific circumstance is the sum of intrinsic, extraneous and germane cognitive load (Sweller, 2016). An increased intrinsic cognitive load can result in a high cognitive load; this could be due to the complexity of the subject. However, it could be due to high extraneous or germane cognitive load which is due to the design of instructional content (Sweller, Van Merrienboer, & Paas, 1998). AR has the ability to improve instructional design with the technological design which directly reduces the extraneous cognitive load and indirectly reduces the germane cognitive load (Brunken, Plass, & Leutner, 2003; Chandrasekera & Yoon, 2015).

Cognitive load in individuals differs according to their processing ability. There is a variation in the processing ability of experts and novices. Cognitive load in experts is less as they have more experience and knowledge in the field. Whereas novices have a high cognitive load as they have no experience (Bobis, Sweller, & Cooper, 1993; Chandler & Sweller, 1996). High cognitive load in individuals causes failure or obstruction in the specified task. Cognitive load is found higher in children and elderly people. Children have less knowledge and processing capacity which causes high cognitive load and aging in elder people causes a decline in processing capacity of working memory which creates high cognitive load (Chandler & Sweller, 1991; Wingfield, Stine, Lahar, & Aberdeen, 1988).

There are two approaches to gauge the cognitive load among individuals: Objectivity and Causal Relation. The objectivity states to the process which employs subjective measures such as self-reported information, perceptions of behavior, physiological conditions, presentations etc. Whereas the causal relation depicts the approaches which depends on the type of relationship of the experience observed by the individual. Table 1.1 describes the classification of different approaches for measuring cognitive load.
TABLE 1.1: Approaches for Measuring Cognitive Load (Brunken et al., 2003)

<table>
<thead>
<tr>
<th>Objectivity</th>
<th>Causal Relation</th>
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<tr>
<td></td>
<td>Indirect</td>
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<td>Subjective</td>
<td>• Self-reported mental effort</td>
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<tr>
<td>Objective</td>
<td>• Behavioral measures</td>
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<td>• Physiological measures</td>
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<td></td>
<td>• Learning Outcome measures</td>
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1.7 Technical Skills

Technical skills can be defined as the ability of the student to perform a specific task. It is also defined as the proficiency required to perform a particular task. Technical skills can be acquired or improved by practicing during learning. Technical skills are often task or domain specific. In engineering education, technical skills refer to the abilities to perform practical and hands-on experiments which can also be termed as laboratory skills. Student enhances their laboratory skills when they perform practical experiments (Barata, Filho, & Alves Nunes, 2015). Laboratory skill increases with more practice in performing a given task such as performing laboratory experiment or operating laboratory equipment. AR has the capability to enhance the student experience, which helps students in improving their laboratory skills (Squire & Jan, 2007).

1.8 Purpose of Study and Research Questions

In engineering education, experiences in laboratories are vital in building the theoretical concepts and reinforcing them by practice. The experience of laboratories is very crucial in enhancing the laboratory skills of students which help them in employability. Electronics laboratory experiences involve designing of circuits and performing real time analysis of the experiments with the help of hardware and software components. In laboratory setup, students have to deal with
sophisticated software and hardware devices which can increase the cognitive load in students. Laboratory setup requires high mental effort from the students to accomplish the experiment. AR technology can be used to reduce the mental effort of students in laboratory. AR can bring more interactivity and also enrich the teaching-learning process.

The following are the reasons that encourage the development of AR learning system for engineering laboratories:

- Due to high cost of the laboratory hardware equipment, it is not feasible to provide an individual setup to each student.
- Due to the busy academic schedule, each laboratory is shared with different classes during the working hours, so each student gets a limited time to work in the laboratory.
- With the rapid growth in the processing capabilities of computer and handheld devices, it is possible to run AR simulation codes on mobile and desktop devices.
- Due to the decreasing cost of internet services.

This research focuses on developing AR learning system and exploring its effects on cognitive load and technical skills of students. This research study intends to respond to the following research questions:

- In terms of laboratory skills, is there any significant difference between the AR intervention and traditional teaching approach?
- In terms of cognitive load, is there any significant difference between the AR intervention and traditional teaching approach?
- In terms of learning motivation, is there any significant difference between the AR intervention and traditional teaching approach?
1.9 Definition of the Terms

Augmented Reality

Augmented reality is an amalgamation of the real and virtual environment. Augmented reality presents a real-world scene to the user in which virtual content is augmented to enhance the user experience.

Cognitive Load

The total mental effort required to put up in working memory during the task is known as cognitive load. Cognitive load is individual specific, it describes the amount of mental and physical effort an individual puts in to think, perceive and remember information.

Markers

A marker is an image or unique patterns which are used in the AR system to overlay virtual content. Markers are generally mounted in the environment (as paper markers) and they are detected with the help of camera using computer-vision techniques. AR system uses tracking techniques to identify the markers present in the environment. After marker identification, virtual content is overlaid on to the markers in the AR scene.

Mental Effort

Mental effort is the amount of mental energy being spent on a particular task by an individual. The amount of mental effort depends upon the task complexity and the experience of an individual with the task. Less experience and more complexity of task can increase the mental effort.

Virtual Reality

Virtual reality alludes to the virtual environment in which the client interacts with virtual things. In virtual reality, virtual contents are designed which possess similar behavior as of real objects. In virtual reality, the user is completely immersed in the virtual world.
**Working Memory**

Working memory is part of human cognition which is responsible for temporarily storing the information for processing. Working memory has a limited capacity but it is very important for logical reasoning, decision making and behavior. Working memory is also termed as short-term memory which holds information for short term only.

**1.10 Thesis Organisation**

The thesis is organized as per the following chapters:

Chapter 2 presents the state-of-the-art literature review of AR and VR applications developed for different topics in science and engineering education. The literature review has been sectioned on the basis of AR and VR applications in science education, language learning and engineering education.

Chapter 3 presents the research methodology adopted for the present study. This chapter consists of the research objectives, hypothesis, details of participants, measurement tools, experiment design, instructional content, and procedures used in the present study.

Chapter 4 explains the development process of Augmented Reality Learning System. This chapter presents the comprehensive insight of the steps followed for the development of AR learning system which mainly includes 3D modeling and AR development.

Chapter 5 presents the results analysis and discussion about the findings of this research work. The chapter presents the hypothesis testing and discussion of hypothesis based on the results. The data analysis of this study is presented as descriptive statistics and inferential statistical analysis. To evaluate the information, the SPSS statistical tool was used.

Chapter 6 presents the conclusion of the present work and suggestions for future research.
Chapter 2

Literature Review

Azuma, (1997) reviews the field of AR, in which 3D virtual graphics were incorporated to 3D real-time environment. It portrays the applications in the areas of manufacturing, medical, path planning, military, visualization, and entertainment. This article describes the characteristics of Augmented Reality frameworks, including a specific description of optical and video mixing methods. The paper also suggests that successful tracking and registration are two foremost concerning issues in structuring successful AR system, also outlined the endeavors to overcome these issues. This overview gives a good beginning to anybody keen on knowing about or utilizing Augmented Reality.

AR and VR technologies have great pedagogical values and are widely used in science education. AR and VR technologies are promising technologies to offer spatial visualization, tangible user interfaces, haptic interfaces to students thus making it easier for them to comprehend the theories. A good amount of research articles has been studied in comparison to comprehend the impact of AR and VR techniques on student knowledge, learning, attitude, motivation, and cognitive load. The literature review is categorized and presented in different sections as influence of AR and VR technology in science education, language learning, and in engineering education.

2.1 Influence of AR and VR in Science Education

Kerawalla et al., (2006) performed a comparative analysis between the AR interface and the traditional method of teaching to evaluate the interaction between teachers and students in science class. The researcher suggested the preceding design constraints for potential advancement of AR solutions: Flexible AR content which enables teachers to adapt easily with AR technology, student must find it easy to operate AR system, the curriculum delivery time of AR-approach should be same as of traditional teaching approach, development of AR system should be done using user-centered design approach.
Jerry and Aaron, (2010) used AR for science education teaching and learning. AR software was used to develop application for Kinematics graph analysis in Physics which were found to be challenging for students to understand. The research comprises qualitative as well as quantitative analysis. The qualitative results showed that AR intrusion have positive impact on student’s learning attitude and quantitative results have showed that AR intrusion have positive impact on student’s academic accomplishment.

Trundle and Bell, (2010) conducted a study to compare the difference in the treatment of three different learning approaches among childhood preservice teachers. The three approaches used in the study was a computer simulation, computer simulation with natural observations and natural observations alone. The computer simulation program was developed to explain the lunar phases of the moon. A total of 157 respondents took part in the exploratory research and were divided into three sections at random. The results of the research suggest that there was no substantial distinction between the three teaching methods in terms of drawing scientific shapes of moon and conceptual understanding about moon phases. The computer simulation group had significantly greater learning gains when learning about moon phases.

Zacharia and Olympiou, (2011) steered research to inspect the contrast in the physics laboratory between physical settings and virtual environments. In the present study, experimental group included a total of 182 college students and the control group included 52 students. The ANCOVA test was used to assess the substantial distinction between the two groups in learning. The experimental outcomes suggested that physical and virtual environment provide similar learning to the students in physics laboratory. However, compared to the control group, physical and virtual laboratories have better gains.

Wang et al., (2012) endeavored to investigate students conduct in collaborative learning environments in various recreation frameworks. Two portable computer supported collaborative learning (CSCL) situations (AR simulation and Traditional simulation) for assisting college students with acquiring physics science knowledge were structured. The study results indicate that collaborative learning was boosted
in both simulation techniques. Especially, learners who have utilized AR simulation shown more consistent collaborative learning attitude. The study presented a novel viewpoint to profoundly observe student learning attitudes and behavior in collaborative learning environment.

**Wang et al., (2012)** carried out a research study in the course of physics to explore the student's collaborative learning. The research aimed to determine the difference in the learning behavior of learners who used two distinct approaches to learning: AR simulation and traditional simulation. The research was performed among 40 learners using a distinct learning strategy and was randomly allocated to two groups. The experimental results suggest that student learned with AR simulation had shown more consistent collaborative learning patterns compared to students of the traditional simulation group.

**Olympiou and Zacharia, (2012)** piloted a research study to compare the impact of three approaches to teaching: physical environment approach, virtual environment approach and a amalgamated approach of a virtual and physical environment on conceptual coherence of the learners in the science laboratory. A total of 70 students have taken part in the research and they were randomly disseminated into three groups. The pre and post-test strategy were adopted to measure the conceptual understanding between the groups. The results suggested that the blended learning approach of combining physical and virtual environments has significantly improved the conceptual understanding of students compared to the other two approaches.

**Olympiou, Zacharias and DeJong, (2013)** presented the concepts of lights and color with the illustration of abstract items to increase the conceptual knowledge of students in the physics course. The study was conducted among 69 participants who were further distributed into two groups: treatment group (N=36) and control group (N=33). The participant from treatment group were treated using simulations with the representation of concrete objects whereas the participant from control group utilized the simulations with illustration of actual objects. The experimental results suggested that the existence of illustration of actual objects was supportive for students to build conceptual knowledge about the phenomenon.
Yen, Tsai and Wu, (2013) conducted a study to assess the effect of various approaches to instructional design on student learning, motivation and learning efficiency in the science curriculum. The different instructional design approaches used in this study includes: 2D animation, 3D animation, and AR technology. The research was carried out among 104 university students and was split into three groups randomly. The ANOVA test was used to evaluate the distinction in mean values between the three groups. The experimental findings suggested that the mean academic performance scores of three groups were similar. In terms of concept learning, AR approach had better outcomes in comparison to the other two approaches. The students of 3D animation and the AR group had a high level of motivation compared to 2D animation group.

Chu and Lin, (2013) built an augmented reality application based on context-aware framework to promote pervasive learning among the students. An inquiry was conducted in a natural science course at primary school to evaluate the adequacy of the proposed methodology to look at the student's exhibition regarding their learning motivation and attitudes, cognitive load, self-efficacy, and academic achievements. From the exploratory outcomes, it was discovered that the AR system has increased the student attention and their attitudes during the learning process.

Hwang, Yang and Wang, (2013) proposed a concept-map approach for creating serious digital games for educational purpose. The approach incorporated the concept mapping into a gaming situation for a better learning experience. An investigation was conducted to assess the effect of the proposed approach on cognitive load, learning gain, and motivation of students. The experiment was conducted among 56 students from two classes of sixth grade in natural science class. The students of one class (N=28) learned with a digital game based on concept-map and students of another class (N=28) learned with a digital game without a concept-map approach. The experimental findings indicate that the concept map strategy considerably enhanced the learning gain of the student and also reduced their cognitive load.
Ferrer et al., (2013) created a unique AR-based simulation application which aims to teach the students about the solar energy design issues and energy usage efficiency. The AR application is a mobile-based learning application gives interactive visualization of the solar simulation and Brownian motion also computes building performance in a simulated environment. The study was performed among 36 students of the college who were split into three groups at random. The three groups used three separate methods: desktop based simulation, AR with a single-marker and AR with multiple-markers. The experimental results suggest that the AR-based system increases task completion time compared to the desktop-based system, which further reduces usability. Also, the users who used AR interfaces are more motivated than the users who used the desktop-based system. In terms of learning, single-marker AR system has increased learning when compared with multiple-marker AR system.

Lin et al., (2013) explored the impact of the AR learning framework on the knowledge construction behavior and learning gains of students.. The researcher has developed a mobile AR system for understanding the concept of elastic-collision in Physics for University Students in collaborative learning approach. The researcher has recruited 40 undergraduate university students and split them into two groups: one group is treated with the AR system and another group is given traditional treatment. The post-test analysis (t-test analysis) of the two groups signify that students learned with an AR strategy have much better achievements in learning. In addition, student behavior patterns suggested that AR can improve learners’ knowledge development.

Kamarainen et al., (2013) piloted a study which aims to evaluate water quality assessment of a lake during the Environment Science Education Visit for learners of the 6th grade. The researcher used the site-learning approach in AR mobile application to enhance the student experience and interpretations about water quality parameters. A total of 71 sixth grade students participated in the research study. The study used interviews and a survey questionnaire to interpret the results. The results indicated that AR has enhanced the attention and learning of the student. The learner-centered activity enhanced student interaction and comprehension of the water quality measurement.
Wojciechowski and Cellary, (2013) developed a learning system based on Augmented Reality Environment Modeling (AREM) approach for conducting chemistry experiments for grade 2 students. The research aimed to measure the learner attitude towards chemistry laboratory using an AR environment. The researchers have implemented technology acceptance model (TAM) questionnaire for measuring learner attitude in AR environment. The TAM model utilized two parameters: ‘usefulness of the system’ and ‘ease to use the system’ to measure the learner’s attitude towards the AR system. The experiment was conducted on 42 participants from grade 2 and the findings proposed that chemistry teaching experiences were liked by learners using the AR arrangement. The use of the AR setting also offers learners with additional motivation.

Vinumol et al., (2013) presented a prototype called Interactive Text Book for learners with learning disabilities. The Interactive Text Book featured normal text and it didn’t include any extraordinary markers or symbols. Once the student focused on a particular text then a relevant 3D image, audio or video that describes the text were augmented on the page. The Interactive Text Book utilized AR technology to overlay virtual graphical content on learner’s optical view. The system allowed the learners to dynamically interact with the virtual graphics which further enhances their understanding and learning.

Chang and Chung, (2014) developed an interactive multimedia based learning environment using AR technology. The aim of AR-based interactive learning system was to equip understudies with the information of plant developing cycle and managing them to learn by performing. The story script displayed the stage-wise growth of flower by utilizing the sequence of multiple markers, and then the AR provides the interaction with 3D graphics. Students utilized the camera to track the multiple markers and then the 3D graphics were produced on the display screen. With the changes in marker and time update of Arduino clock, the mixed reality system presents the development process of flowers to students which brings excitement during learning. The experimental results revealed that interactive multimedia learning platforms increases motivation and encouraged the students to learn. Also, learning by doing enhanced the student practical experience which improves the knowledge retention during the learning. The student’s opinion
suggested that they particularly relished the method of hands-on learning as it allows them to undertake diverse things.

**Ferrer-Torregrosa et al., (2015)** developed ARBOOK which is a learning tool based on AR technology. ARBOOK focused to give knowledge about the structure of the lower limb. ARBOOK is a sign marker AR software consisting of a computer screen, webcam, and paper markers. ARBOOK presented 2D images, 3D models of limb and text to enhance the student experience. Client can be associated with the system by rotating and moving the paper markers. The study was conducted among 211 university students and they were distributed randomly into two group: treatment group (N=77) and control group (N=134). The treatment group students learned through ARBOOK and the control group students were instructed through conventional lectures, slides, and videos related to the subject. The objective of the research was to calculate AR's influence on student understanding, learning motivation and attention. The experimental results suggested that students who learned through ARBOOK had significantly scored better in the written test and had a high level of motivation and attention.

**Purnama, Andrew and Galinium, (2014)** explored whether OpenCV is able to create AR-based applications or not. With the capacities of OpenCV in identifying the color and overlaying 3D graphics in the real environment, it bolsters the AR application development. The exploratory research was accomplished by making the Augmented Reality Geometry Learning Tool Framework which depends on OpenCV to assist primary school students learn how to use protractor for angle measurement. The model framework was deployed on the primary school students to get the feedback of the understudies. The feedback from the understudies was fulfilling and it demonstrated that OpenCV is able as the library to develop AR applications.

**Santos et al., (2014)** reviewed the AR applications developed specifically to supplement conventional educational materials for K-12 education. In the meta-analysis provided, the research study showed that augmented reality learning environment (ARLE) accomplished a broadly adaptable impact on student academic performance from a little negative effects to the large effects. Also, a
quantitative analysis on design aspects of ARLE was completed which mainly includes software tools, display devices and techniques, authoring tools and evaluation strategies. The paper also described the three characteristics advantages of AR system which were contextual visualization, real-world explanation, contextual conception, and vision-haptic conception. The experiences from this survey paper can be useful in planning the future ARLEs.

**Cai, Wang and Chiang, (2014)** Anil led a research to determine how AR simulation technique influences student understanding and teaching motivation for grade 2 learners in chemistry class. The investigator used AR-based teaching tool to comprehend the chemical microstructures of atoms. The findings stated that in weaker students, the AR teaching method has significantly evolved the learning outcomes and gains in learning.

**Ibáñez et al., (2014)** conducted a study comparing AR-based application with web-based application in terms of academic improvement and involvement of students in the task. The researcher used the web-based and AR-based application to teach basics of electromagnetism to grade-12 students. The experimental results suggested AR as a more efficient approach in learning electromagnetism and providing a better visual representation of concepts. The experimental results suggested that AR technique has been more efficient in studying electromagnetism and providing improved concept visualization. The AR-based framework provides a higher flow experience than the web-based application.

**Chiang, Yang and Hwang, (2014)** developed a location-enabled mobile AR framework using a learning approach based on inquiry. In a science course, the AR environment helped the student learn about aquatic plants. The study was conducted among 57 fourth grade students and results indicated that AR-based educational practice has more stimulating knowledge-building relationships compared to conventional inquiry-based learning.

**Chiu, DeJaegher and Chao, (2015)** developed an augmented virtual laboratory experience for understanding the gas properties in science education. The system associated virtual experience with physical laboratory experience to enhance student’s observation of the molecular level phenomenon. The system utilized
sensors to provide physical inputs for scientific simulations. Around 45 learners in grade-8 participated in the research study and results revealed that augmented virtual lab enhanced the student’s understanding of molecular level phenomena of gases.

**Chen and Liao, (2015)** directed an exploratory study to determine the influence of AR and guiding strategy on student performance and learning motivation in electrochemistry concepts. 152 High school freshmen participated in the research study and were randomly split into four groups based on the sort of AR and guidance approach. In the study, two types of AR (static-AR and dynamic-AR) were used and two types of guiding strategy (procedure-guided and question-guided) were used. The experimental results suggested that while delivering static AR, procedural guidance group had better learning gain compared to question guidance group. Also in terms of knowledge and understanding, the static-AR group had outperformed the dynamic-AR group.

**Chen and Wang, (2015)** conducted research to observe the impact of instruction strategy and teaching style on learning accomplishment and motivation when learning through AR embedded learning method. The experimental investigation was conducted among 144-grade eighth school students. There were three groups of participants based on distinct learning styles: single mode, dual mode, and multi-mode. The independent sample t-test and ANCOVA test were conducted to relate the results of the three groups. The experimental results suggested that learning styles significantly affects the learning achievement and AR has enormous potential to provide hands-on experience to the learners.

**Akçayır et al., (2016)** Alex performed an investigation to evaluate the impact of AR technology on student laboratory capabilities and their laboratory attitudes. The study was conducted on 76 university students in the physics laboratory. The researchers had distributed the students into two groups: the treatment group and the control group. The treatment group was given AR treatment and control group were given conventional teaching in laboratories. The AR application was designed for five experiments in the physics laboratory. The videos, graphics, and link to supplementary materials were augmented as AR components. The experimental
results suggested that AR had significantly enhanced the laboratory skills and had a substantial optimistic effect on the students’ attitude towards laboratories.

**Chao et al., (2016)** performed research to compare the learning outcomes of two classes in the chemistry laboratory that used distinct teaching strategies to comprehend the gas characteristics. The experimental group was trained using Augmented Virtual Lab and control group were trained using a teacher-led physical laboratory. The study results suggested that students who learned through Augmented Virtual Lab had significant better learning gain compared to students of traditional teaching approach.

**Skulmowski et al., (2016)** developed a tangible user interface (TUI) for university students to understand the human heart anatomy. The system consists of a 3D model of human heart and students can interact with it using the tangible object which uses motion tracker for interaction. The research aimed at assessing the effect of the TUI system on learning, cognitive load and motivation of students. The experiment was conducted among 96 university students and randomly divided into four groups: mouse with a perpetual display, mouse with selective pointing, TUI with perpetual display and TUI with selective pointing. The experimental results suggested that TUI offers better learning gains.

**Lindgren et al., (2016)** developed a whole body interaction simulation system with the use of mixed-reality technology. The system aims to engage students in learning about planetary astronomy in physics. The research aimed at comparing the entire body interaction scheme with a traditional desktop-based scheme in terms of student learning, behavior and engagement. The results revealed that the entire body-based interaction scheme considerably enhanced learning, encouragement, and behavior of students towards science education.

**Hwang et al., (2016)** designed an AR-based game using competitive gaming approach for learning about the ecosystem of butterflies in natural science class. The study was conducted among 57 grade, five students. The participants were distributed into two groups: Group A (N=30) and Group B (N=27). The students of the Group A were imparted education through AR game with competitive approach and students of the Group B were imparted education through
conventional AR game. The experimental results suggested that AR-based competitive game can improve student performance and learning attitudes in educational field trips.

Huang, Chen and Chou, (2016) developed an innovative learning experience by combining AR technology with Kolb’s experiential learning cycle in a botanical garden setting. According to Kolb’s experiential learning, learning is the process of experience conversion and comprises of four continuous and cyclic stages: Practical experience, interpretation, and observation, abstract ideas and generalizations, testing in real-time conditions. The researchers had developed an AR-based learning system which allowed the student to interact with environmental material in a botanical garden and enable them to had an immersive experience of the environment. The research aimed to assess the impact of AR technique on sentiment and learning outcomes in environmental education. The research was carried out among 21 students of middle school who were arbitrarily spread into three groups named as Group X (N=7), Y (N=7) and Z (N=7). Group X was instructed using the AR approach for self-learning, Group Y was instructed using the AR system along with observer supervision and Group Z utilized conventional experiential learning. The investigational findings suggested that AR-based learning methodology was better than the conventional learning methodology in terms of emotions and learning outcomes.

Salmi, Thuneberg and Vainikainen, (2017) piloted a study to analyze the impression of AR technology on learning achievements, learning motivation and cognition. The study was conducted among 146 participants aged between 11 to 13 years visiting the science centre exhibition. The experimental results recommended that AR technology was more beneficial to the low-achievement groups and girl participants. Situated-learning and learning attitude in science exhibition was more strongly associated among boys than girls.

Chang and Hwang, (2017) proposed a mission-based peer support technique to improve the learning of students in a computer gaming situation. An experiment was performed among 65 learners from two classes of seventh grade in natural science class to assess the effect of the proposed method on student learning,
attitude and collaboration skills. The experimental group (N=34) was taught with a digital game developed using mission-based peer support technique whereas the control group (N=31) was taught with a digital game without mission-based peer support technique. The investigational outcomes recommended that the proposed method had positive impressions on student learning and attitude in science class. Also, the mission-based peer support technique enhanced the student’s collaborative skills and inspired them to offer support to their peers during learning through game.

Chang and Hwang, (2018) conducted a study to compare the AR-based flipped learning strategy with the traditional flipped learning strategy in terms of learning achievement, project performance, critical reasoning, cognitive load, self-efficacy, and learning motivation. The experiment was conducted among 111 students of grade five. The students were arbitrarily dispersed into two groups and were given different treatments. The results recommended that AR-based flipped learning strategy had a beneficial effect on project performance, motivation for learning, critical thinking and self-efficacy but no substantial impact on the learning achievements and cognitive load were found.

Achuthan, Kolil and Diwakar, (2018) designed a virtual laboratory environment to teach molecular symmetry in chemistry education. The virtual laboratory consists of various simulation and geometrical representations of molecules, an assessment tool for measuring the understanding of molecular symmetry concepts, and molecular symmetry operations. A study was conducted among 90 graduate students in chemistry using the designed assessment tool. The students were distributed into two groups randomly: treatment group (N=45) and control group (N=45). The participants of the treatment group were trained with virtual laboratory environment and the participants of the control group were taught with textbook learning. The experimental outcomes suggested that virtual laboratories had significantly enhanced the student understanding about the molecular symmetry in chemistry class.

Bumbacher et al., (2018) used simulated and physical manipulative settings for conceptual comprehension of two subjects in inquiry-based science teaching: Mass
and spring; Electric circuits. The study's objective was to identify the relationship between experimental approach, conceptual comprehension and learning outcomes. The experimental study was completed by 58 college students and findings suggest that manipulative environment with more productive experimentation strategies results in better conceptual understanding among students.

**Gould and Parekh, (2018)** used a multimedia based mentoring game to mentor and engage schoolchildren in the science curriculum. The mentoring game was inclined and developed for Mystery of Taiga river for science education. The research aimed to determine the effect of game-infused science curriculum on argumentation practices and discourse practices of students. Around 57 middle school students took part in the experimental study and they were arbitrarily distributed into two groups: experiment group (game-infused treatment) and control group (traditional treatment). The study results suggested that the students mentored through game-infused science curriculum had better engagement and high level of argumentation.

**Lamb et al., (2018)** steered a study to observe the difference in hemodynamic response of students using four different learning approaches in science education. Serious educational games, VR, video lectures and hands-on activities were used as different learning approaches. A total of 100 college students took part in the experiment and were randomly distributed into four groups using different learning approaches. The Functional near-infrared spectroscopy technology was used to measure the cognitive dynamics of the student. Data acquisition and visualization have ensued with the help of Cognitive Optical Brain Imaging Software Studio. The results suggested that VR and Serious educational games had positive impressions on attention, critical thinking and cognitive abilities as compared to video lecture and hands-on activity approach.

**Kapici, Akcay and de Jong, (2019)** piloted a study to compare to the influence of applied and virtual laboratories offered in different arrangements on student knowledge acquiring and inquiry skills in science laboratories. The topic of electricity from seventh-grade science curriculum was selected to conduct the experiment. The research was attended by 143 seventh grade learners from four
different classes. The students were split into four groups based on experimental research design and assigned to different conditions as: VVV, HHH, VHV, and HVH where V stands as virtual laboratory and H stands as a hands-on laboratory. To measure the conceptual knowledge acquired amongst students, multiple choice questions and open-ended questions based test was employed. The findings showed that blend of virtual and hands-on laboratories such as VHV and HVH gives significant better learning outcomes when compared with using virtual laboratory alone. Also, no substantial difference in learning gains and inquiry skills of hands-on laboratory (HHH) alone group and virtual laboratory (VVV) group were found.

**Wang and Tseng, (2019)** conducted a research study to identify the usefulness of static and dynamic visualizations on the spatial abilities and learning of students. The researcher used two different approaches of visualization to teach star motions. In static visualizations, students were taught with the help of static images explaining star movements during the night and different star constellations at different time of the year. While in dynamic visualizations, videos and animations related to star motions and constellation were presented to the learners. The study results indicate that the dynamic visualizations are more beneficial for comprehending difficult concepts. Also, spatial abilities of students have substantial beneficial effect on the learning of students.

**2.2 Influence of AR and VR in Reading and Language Learning**

**Liu and Chu, (2008)** developed a handheld AR that endorsed pervasive learning to improve students' English language learning. The system framework incorporates the AR technology with sensors, pervasive computing, and ICTs. The learning system comprises two subsystems: English language learning management system and English language learning tool. The study was piloted in junior high school and evaluation results suggested that the AR intermeditation has enhanced the English language learning and motivation among the students.

**Yuan-Jen Chang et al., (2011)** employed an AR educational game for improving English language of the students. The study was conducted to gauge the effectiveness of AR educational game on student behavior and satisfaction. The experimental results suggested that the system quality was an important factor in
enhancing student satisfaction and usefulness of the system. The perceived self-efficacy was directly correlated to the perceived usefulness and satisfaction. Also suggested that the AR software design framework should be easy so that learners can adapt more easily to the latest technology.

Mau-Tsuen Yang and Wan-Che Liao, (2014) developed an AR-based interactive learning environment called VECAR which utilizes free-hand gesture interaction using computer vision techniques. VECAR utilizes computer vision techniques to capture free hand-gestures and then further combines the virtual objects to the tabletop environment. VECAR provides an interactive and immersive educational experience to the students. The aim of AR environment was to provide English language learning and cultural learning to the engineering students. The study results suggested that AR environment had improved the cultural and language learning skills of the students and also enhanced their interpersonal communication skills.

Hsu, (2017) Developed two AR-based learning games on an autonomous learning strategy and a task-based learning strategy. Both the educational games aim to help in learning English vocabulary. Self-directed learning method did not confine in learning sequence as the learner was free to learn in any sequence of their choice. While in task-based learning method, the sequence of learning was limited The experimental findings suggested that learners with autonomous learning strategy had a better flow and that learners with a serial learning style had low mental effort and learning discomfort. It was also observed that learners with a global learning technique do not use assignment-based AR as it elevates mental stress and learning discomfort leads to limited learning benefit.

Rau et al., (2018) directed a research which aims to compare the reading performance of students on the AR and VR system with a traditional desktop system. The participants were 63 college students and were distributed into three groups based on the AR system, VR system, and Desktop system. The participants were given tasks to read the Chinese language at different speeds followed by multiple choice questions. The experimental outcomes proposed that the reaction
time on the AR / VR system when reading at standard and fast velocity was
ten percent higher than the LCD device.

**Bursali and Yilmaz, (2019)** conducted a study to evaluate the effect on reading
comprehension and learning permanence of AR applications. In the research, an
AR application for reading comprehension was created on Aurasma software. The
study was conducted among 5th-grade students and 89 students took part in the
study. The students have been divided into two groups. The students of the
treatment group used AR application for reading activities while the students of
control group used traditional teaching approach. The findings proposed that the
learners taught by employing AR had a high degree of understanding in reading and
learning permanence. Also, the student learning through AR application exhibited
low level of anxiety.

### 2.3 Influence of VR in Engineering Education

**Yu Sheng et al., (2011)** developed an AR framework pertaining to the daylight
modeling of the building architecture. The AR framework allows the user to
simulate the daylight and explore different architectural designs to enhance the
global illumination of the building. The application utilized camera to captures the
real world images and processes them to convert into 3D models. The application
utilized hybrid rendering technique for interactive rendering. Four calibrated
projectors were used to combine the rendered images on the real model. The
participants had collaboratively studied the daylighting illumination and redesign
the building structure and saw the efficient illumination conditions through AR
simulation.

**Barata, Filho and Nunes, (2015)** developed a VR-based Virtual Technical
Instruction (VTI) system to comprehend the operation of power transformers in
electrical power substation. The purpose of the research was to enhance students’
knowledge about electrical equipment used in the practical situation of a power
substation. With the help of VR technology, a concrete illustration of power
substation was being presented to the students who rarely had access to visit these
scenarios. The experiment was conducted among electrical engineering students
and students were provided VTI system to perform virtual simulation about
operating and performing maintenance of electrical equipment. The experimental results suggested that the VTI mechanism enhanced student efficiency and motivation for transformer learning.

**August et al., (2016)** created a Virtual Engineering Science Learning Lab (VESLL) to teach learners in engineering the basics of digital electronics. VESLL is VR-based interactive learning environment that provisions STEM learning, with a prospect to engage and help women and other understated individuals. VESLL enables learners to numerous quantitative skills and conceptions by using collaborative games, visualization, and problem-solving skills with realistic learning practices. The research was carried out among students of engineering and information was collected using knowledge test and survey questionnaires. The student’s reaction to the VR-based learning lab was encouraging.

**Garcia-Zubia et al., (2017)** created a Virtual Instrument System based Remote Lab (VISIR) to teach concepts of analog electronics to electrical engineering students. The study's objective was to evaluate the effect of the remote laboratory on the student learning method. The information was gathered using pre- and post-test design. The Wilcoxon test was used to evaluate the outcomes of knowledge test scores. The findings suggest that remote laboratories have a beneficial effect on the learning of students.

**Akbulut, Catal and Yildiz, (2018)** developed a Virtual Reality Enhanced Interactive Teaching Environment (VR-ENITE) to teach computer science engineering students about data structures. The VR-based system was focused to help students in understanding the sorting algorithms such as merge sort, bubble sort, insertion sort, and selection sort. A study to determine the effect of the VR-ENITE system on the academic performance of students was conducted. A total of 36 students in computer science engineering participated in the research and were arbitrarily split into two sections: treatment section and control section. The learners of the treatment section were trained using the VR-ENITE system and traditional training was given to the learners of the control section. According to research outcomes, students who utilized the VR system had gain of 12% in test scores when compared with students who learned through traditional teaching treatment.
Rosero-Zambrano et al., (2018) steered an experiment using a blend of the regular classroom and virtual learning instrument for engineering students in the basic electronics course. The study aimed at measuring the influence of the virtual learning instrument on the knowledge and attitude of the student. The experimental results suggested that the virtual learning instrument promotes student self-learning and improves academic achievement.

Ouyang et al., (2018) developed Unity-3D based interactive virtual learning environment which help students understand how a chemical plant works and operates in chemical engineering. The virtual learning environment provides two types of walkthrough mode and allows the student to operate the main equipment, major pumps, and valves of the chemical plant in a virtual environment. The assessment of the system was conducted using a survey questionnaire designed for five perspectives: accessibility, immersion, easiness, helpfulness, and requirement. The student feedback to the survey questionnaire suggested that the virtual practice platform assisted the students to understand the plant's chemical process and equipment.

Zhang et al., (2018) developed a virtual learning environment for Weft-knitting engineering. The system allows the undergraduate students of textile engineering to understand the technical design aspects of textiles. The system allows the student to virtually see the weft-knitting process and virtually practice the machine. The experimental results suggested that the virtual system enhanced the student's operational abilities and teaching efficiency about the system. The student feedback suggested that the 3D virtual learning system was effective and provides an immersive experience to the learners.

Achuthan, Kolil and Diwakar, (2018) developed a virtual laboratory environment for understanding the molecular symmetry in chemistry education. To understand the molecular symmetry in chemistry course requires high visual-spatial skills, the virtual laboratory was focused to enhance the student visualization and spatial ability. The virtual laboratory had significantly improved student visualization and spatial abilities in molecular symmetry concepts. The experimental results showed a substantial enhancement of 156% in the understanding of molecular symmetry.
conceptions after exposing undergraduates to the virtual laboratory environment. The interactive virtual laboratory environment was effective in identifying bond angles and planarity in molecular chemistry.

Alfalahl, (2018) performed a research to analyze the faculty perception of utilizing VR as a teaching tool in information technology courses. The study was conducted among 11 instructors of engineering. The survey questionnaire consists of 25 questions based on instructor perception towards VR, the importance of VR, and applicability of VR as a teaching tool. The study outcomes indicate that instructors were highly willing to adopt VR technology as a teaching aid. The results also recommended the requirement of VR technology training to successfully impart VR into the teaching process.

2.4 Influence of AR in Engineering Education

Andujar, Mejias and Marquez, (2011) proposed a concept of Augmented Remote Laboratory (ARL) which is also one of the application areas of AR, where a learner can access the expensive laboratory equipment from the remote areas. AR is very beneficial where laboratory equipment is expensive or have limited hardware and software resources. In engineering institutes, it is very challenging to equip each student with an individualized material, also students have limited time to work in the laboratory as the same laboratory is shared with different courses and classes. ARL allows the learners to interact with real laboratory equipment from remote locations and student gets the real experience assuming that they are physically present in the laboratory. In this way, laboratory equipment can be accessed 24 hours a day.

Mejías Borreto and Andújar Márquez, (2012) developed an Augmented Remote Lab (ARL) for teaching concepts of a digital system, and robotics and industrial control for electronics engineering students. The AR-based remote lab system allows the students and teachers to work remotely in a classroom lab using internet services. The study was conducted among 20 students and 10 teachers and both groups were given the experience of classroom lab, virtual lab, and ARL. The experimental outcomes suggested that ARL had significantly improved the student experience and learning.
Matcha and Awang Rambli, (2012) designed an AR interface which aims to examine the association between current and resistor in a electricity course. AR application uses a camera to capture paper markers, then AR technology overlays the 3D virtual objects. Each marker signifies different components of the electric circuit. The 3D virtual objects were designed to represent the electric circuit components which have enhanced the student understanding about the electric circuit.

Phon, Ali and Halim, (2014) conducted a state of art literature review related to the AR applications developed for collaborative learning. The author had reviewed the AR applications of collaborative learning on the basis of educational benefits and challenges faced to implement the system. The author has suggested that AR has an advantage of presenting the real environment superimposed by the virtual information which provides better visualization to the learner. AR has the capability to present the learning content in 3D perspective which enhances the understanding of difficult concepts as the student can visualize the phenomenon. Although AR has certain advantages but has few challenges also in terms of usability and demonstration. The author had reported that AR application with GPS reports error which causes frustration to the student while using the application. Also, a lot of information is presented to the user while using the AR application which causes high cognition among the students. So, learning content in AR needs to be properly managed and designed.

Restivo et al., (2014) presented an exploratory research to understand the potential of AR in teaching DC circuit fundamentals. The study aimed to measure the student participation for understanding about DC circuit fundamentals using AR application as an educational tool. The study explained the process of the AR application development and discusses the student experiences with AR learning tool. The experimental results suggested that AR application was an effective learning tool and enhanced student learning. Also, AR has great potential for developing educational learning tools.

Cubillo et al., (2014) created an augmented reality learning environment which could be used by both academicians and students. Teachers can use the ARLE to
develop learning resources for educational purposes and students can utilize the ARLE for gaining knowledge in the specified domain. The authoring tool of ARLE allows the teachers to include different resources such as pictures, videos, audio and 3D graphics in the learning resource. It also allows the teachers to include multiple choice questions for setting up an exam for students and also provide an inventory of virtual resources. In this paper, ARLE was utilized to develop AR applications for a textbook which provides AR experience to the students along with theoretical experience.

Perez-Sanagustin et al., (2014) presented three blended learning activities utilizing AR technology in a formal and informal educational setting. The paper presented the design of learning activities by blending GPS and NFC technology in AR environment used for teaching and learning purposes. The paper contributes towards educational perspective and technological perspective of AR technology used in formal and informal educational pedagogy. The paper provided insights into the design process of AR learning environment which was useful for future research applications.

Kraut and Jeknic, (2015) developed different AR-based applications for vocational training and education. The research work was done under the project named ARAVET (Augmented Reality Application on the Field of Vocational Education and Training). In this project, AR applications related to operation of sewing machine in textile industry and working of electronic circuits like diode and logic gates was developed. The 3D animations and virtual simulation were developed to improve the educational experience of the students. The findings of the research proposed that AR technologies could enhance the learning of the student and the user experience. While there was limited hardware to experience AR. So next generation user interfaces with multisensory way can improve the AR experience.

Martín-Gutiérrez et al., (2015) used the AR technique to create practice manual in the electrical engineering laboratories for practicing electrical machines. The AR-based practical manual is a mobile-based application which instructs the student to perform practical experiment on electrical machines. The exploratory
study utilized system usability survey questionnaire and survey results suggested that AR-based laboratory manual had encouraged autonomous and collaborative learning among students also it had reduced the teacher’s effort while conducting the experiment.

Lee et al., (2016) developed an interface for engaging students and industry experts using hybrid video conferencing system with a 3D virtual world environment. Using the interface, students presented their project thoughts at the virtual trade fair to industry professionals to get feedback at the start-up stage. The study was carried out to measure the methodology’s effectiveness in improving performance and self-efficacy of students in project-based learning. The data were collected through survey questionnaires from students and industry experts. The study results signify that hybrid video conferencing system had improved the student self-efficacy and performance in project-based learning.

Rodriguez-Gil et al., (2017) proposed a new model of Augmented remote lab in web-based design. The paper discusses a hybrid laboratory approach that interacts with actual and virtual parts. The lab architecture is completely web-based using HTML5 and WebGL5 standards. The proposed architecture allows using Unity technology in web-based design. The system was implemented at Watertank-FPGA hybrid laboratory at the University of Deusto, Spain. The study was conducted among 58 first-year engineering students and results suggested that hybrid laboratory had valuable learning ability and is extremely encouraging and interactive.

Frank and Kapila, (2017) developed a Mixed Reality Learning Environment (MRLE) to enrich student interaction with laboratory hardware in engineering laboratories. The MRLE allows the learner to point mobile devices towards laboratory test-bed with fixed artificial markers and then mobile AR application provides the real-time scene with interactive virtual media to support and enhance the learning. The objective of the research was to determine the effect of MRLE on student knowledge and machine operation understanding. The experimental findings indicated that the learners who taught with MRLE enhanced their
understanding considerably. Also, in terms of system usability questionnaire, students had given positive feedback about MRLE.

**Reyes-Aviles and Aviles-Cruz, (2018)** has created a mobile educational framework based on AR with markerless tracking for understanding resistive circuits in electronics engineering. The AR-system is a mobile-based application which utilized smartphone camera to capture electric circuit and calculates the value of voltage and current across the resistor. The AR application generates a virtual layer to display the values of voltage, current, resistance and power on the smartphone screen. The technical efficiency of the developed AR system was 98%.

**Tumkor, (2018)** developed an educational mobile application using mixed-reality (MR) technology. MR technology enables learners to view and communicate with the 3D representation of 2D sketches. An experiment was conducted in engineering drawing classes to analyze the effect of MR technique on visualization skills of engineering undergraduates. The study utilized mental rotation test in pre and post-test design strategy for data analysis. The experimental results revealed that MR-based mobile application can effectively improve the visualization skills of students.

**Avilés-Cruz and Villegas-Cortez, (2019)** created a mobile AR application to assist engineering students learn about digital integrated circuits. The mobile AR utilizes smartphone camera to capture the real-time images of integrated circuits (IC) and then it uses SIFT algorithm to identify the IC number. Upon the identification of IC number, AR software generates a layer of virtual information which consists of pin diagram and schematic diagram of the IC. The AR system is capable of identifying 7 logic gates and the system efficiency was found to be above 97 percent.

**Karadoğan and Karadoğan, (2019)** developed three haptic-augmented learning activities to comprehend the concepts of dynamics for engineering students. The learning system offers students with both visual and haptic input. The learner can set the parameters, compare results, interact with graphics and experience the tactile interface. The research intends to assess the impact of the system on students’ conceptual knowledge. The research findings reveal that the haptic system has improved learners’ understanding and interest.
2.5 Human Cognition and Memory limitation

Paas, (1992) conducted a study to analyze the differential effects of three different computer-based training approaches on performance, transfer performance and cognitive load. The three training programs were based on traditional problems, worked-out problems, and conclusive problems. The study results revealed that training with conventional problems would require additional time and more exertion. The worked-out methodology was superior to the conventional strategy for achieving transfer. Additionally, it explained that Cognitive load is a multidimensional notion with two primary parts – mental load and mental effort. The mental load was enforced by instructional design and mental effort alludes to the sum of mental energy that’s apportioned to instructional loads.

Paas and Van Merriënboer, (1994) suggested an instructional design model which emphasizes to control the cognitive load using instructional design during the complex cognitive tasks. The instructional design model should optimize the cognitive load so that cognitive load should decrease significantly in complex cognitive tasks. Also, instruction should focus on those characteristics of learning to accelerate the transformation of intellectual abilities obtained. So the identification of component skills is very essential for designing an effective training strategy which will reduce cognitive load. The study showed the interrelation between cognitive load and instruction which further results in effective training approaches.

Sweller, (1994) illustrated the components that can support in deciding the intricacy of instructional material amid the learning procedure. It was suggested that scholarly exercises, theory accomplishment, and automation are the main instruments of learning. Cognitive load intersects with learning and critical thinking capacities which could be affected by the educational plan. Intrinsic cognitive load is static for a specified domain as it is linked with the complexity of the subject. Also, high extraneous cognitive load is caused by high element interactivity during learning. In situations of low element interactivity, re-designing the instructional plan for reducing extraneous load may have no substantial consequences. The notion of communication between elements can be used to clarify the learning
impact of instructional content. It was observed that high element interaction with instructional material causes a high cognitive load among learners.

**Ericsson, (1995)** proposed that working memory is categorized into two accounts: long term working memory and short term working memory. Long term working memory refers to the permanent storage of information that can be used for skilled use whereas the short-term working memory relates to temporary information storage. In long term memory, information is stored in a stable form which could be retrieved only by the means of short term memory. The memory abilities obtained also enable learners to use long-term memory as an effective expansion of short-term memory in a particular domain. According to the author, individuals rely on a particular mechanism to retrieve needed information in long term memory. Individual recovers acquired knowledge using retrieval cues that are referred to as retrieval structures. Also during the interruption of skilled events, long-term operating memory storage of information will remain in long-term memory and can be simply recalled by the recurrence of required retrieval cues.

**Sweller, Van Merrienboer and Paas, (1998)** described the cognitive architecture and its significance in instructional approaches. The architecture demonstrated that the working memory processed educational material. Working memory has a limited capacity, but if information can be processed using both auditory and visual channels, its capacity can be improved. The data processed by working memory can be stored in long-term memory as a permanent store of knowledge. The components of low interactivity can be learned without putting the heavy mental load, so they may be regarded to have low intrinsic cognitive load. Whereas the components of high interactivity cause high intrinsic cognitive load.

**Brunken, Plass and Leutner, (2003)** described the numerous approaches for the measurement of cognitive load induced by instructional design. The measurement methods of cognitive load in multimedia instruction are mainly from the following categories: indirect, subjective or both. The paper described the theoretical background and real time application of dual-task method for measuring cognitive load. The paper also presented a computerized tool for measuring cognitive load.
which provides a direct and objective measures to overcomes several limitations of other indirect and subjective methods.

**Paas et al., (2003)** described the measurement techniques for measuring cognitive load with regard to cognitive load theory (CLT). CLT was emphasized on the structure of instructional techniques that effectively utilize individuals 'constrained cognitive ability to apply gained knowledge and aptitudes to changing circumstances. The characteristics of human cognition style allows to design unique and effective instructional design approaches. The research indicated that the amalgamation of performance and cognitive load assessments are important in assessing the mental efficiency of instructional approaches.

**Sweller, (2016)** described several characteristics of human cognition that are essential to instructional design. There is a difference between generic cognition and domain-specific knowledge. For example, learning to speak and listen to native language requires genetic cognition which will develop during the different evolutionary period and utilize different cognition developments. This requires primary knowledge to be processed and requires less effort during the learning process. Whereas while learning domain-specific topics in educational institutions requires secondary knowledge and different cognitive processes to acquire knowledge. The achievement of secondary knowledge inclines to be demanding and requires sensible effort. Also, secondary knowledge is conquered with the help of primary knowledge. The primary knowledge establishes those cognitive abilities which are generic whereas secondary knowledge inclines to be field-specific. Explicit training is required to acquire domain-specific knowledge while generic knowledge can be attained deprived of explicit training.

**Hadie and Yusoff, (2016)** performed a research to evaluate the legitimacy of a cognitive load scale by internal consistency and construct validity in a problem-based learning environment. The research was performed during a problem-based learning activity among 93 medical learners. Confirmatory factor analysis was implemented using the Analysis of Moment for measuring construct validity. The findings indicate an acceptable amount of goodness-of-fit indicators on the three-factor scale. The internal reliability was also assessed utilizing SPSS software. The
Cronbach’s alpha for intrinsic cognitive load, extraneous load, and self-perceived learning were 0.88, 0.82 and 0.95 respectively, showing good internal consistency reliability. The study results recommended cognitive load scale as a dependable and effective tool for gauging cognitive in problem-based learning scenarios.

### 2.6 Research Gaps Identified

AR and VR is widely used in science education for developing learning experiences. A considerable amount of research articles has been studied on the use of AR and VR in education to examine the influence of AR and VR on student academic achievement, learning, motivation, skills and cognition. The objective of this review of the literature is to find similar learning experiences in science, language learning and engineering courses based on AR and VR and also understanding the assessment technique for assessing laboratory competences, cognitive load and learning motivation. In the field of school science education, many prominent studies are available and research has supported the use of AR technology for science education. In engineering education, although a lot of AR and VR-based learning experiences were developed by researchers and academicians but, there are very limited studies in electronics engineering laboratories. This provides an opportunity to explore and develop an AR-based learning environment for electronics engineering laboratories. In this study, we propose yet another exploratory experiment to gauge the effectiveness of using AR in engineering labs specifically in electronics engineering.
Chapter 3
Research Methodology

This chapter presents the research methodology adopted in the present study. The chapter consists of the research objectives, hypothesis, details of participants, measurement tools, experiment design, instructional content, and procedures used in the present study.

3.1 Research Objectives

This research emphasizes on the following research objectives:

1. To develop an AR Learning System for undergraduate engineering students in instrumentation domain.
2. To analyze the impact of AR Learning System on student’s cognitive load.
3. To analyze the impact of AR Learning System on student’s technical skills in the instrumentation domain.
4. To study the impact of changes in features of AR Learning System on student’s cognitive load and technical skills.

3.2 Research Hypothesis

The objectives of this research study can be achieved by testing the following hypothesis:

**Hypothesis 1:** There will be no significant difference in the technical skills of students of AR treatment group and Traditional teaching group.

**Hypothesis 2:** There will be no significant difference in the cognitive load of students of AR treatment group and Traditional teaching group.

**Hypothesis 3:** There will be no significant difference in the learning motivation of students of AR treatment group and Traditional teaching group.
Hypothesis 4: There will be no significant difference in the technical skills of students of AR treatment group when the design framework of AR Learning System will change.

Hypothesis 5: There will be no significant difference in the cognitive load of students of AR treatment group when the design framework of AR Learning System will change.

3.3 Participants

The aggregate number of engineering undergraduates across India is too vast to even consider experimenting with, so comparatively small set of students were chosen in this study. Sampling refers to choosing comparatively a small number of people, called subjects, to discover something about the whole populace that the subjects represent. The present research aims to develop an AR-based learning system and determine its effectiveness on technical skills and cognitive load of undergraduate engineering students. Research participants of this study are undergraduate engineering students of Chitkara University, Punjab, India. A total of sixty 1st year engineering undergraduates from the 2018-19 academic year have took part in the study. The students were in the 2nd semester of their undergraduate engineering program during the course of this study. The participants have no or very less knowledge of laboratory equipment. The participants don’t have any understanding and knowledge about AR. At the start of the experiment, the students were distributed randomly into two different groups: Treatment group and Control group. The treatment group (N=30) and control group (N=30) contains equal number of males and female participants. The details of the participants are given in Table 3.1. Treatment group students were taught with AR and control group students were taught with conventional teaching approach. To evade the teacher influence on experimental outcomes, both groups were taught by the same teacher.
### TABLE 3.1: Participants Details

<table>
<thead>
<tr>
<th>Gender</th>
<th>Number of Students</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treatment Group</td>
<td>Control Group</td>
</tr>
<tr>
<td>Male</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Female</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

#### 3.4 Research Design

The present research was aimed to determine the influence of AR intervention on student cognition and technical skills. The experimental research design consists of the following activities presented in Figure 3.1.

![Fig. 3.1. Research Design](image)

The experimentation was outlined in the electronics laboratory facility of Chitkara University, Punjab, India. In electronics laboratory, undergraduates were acquainted with the essential electronics measuring hardware like oscilloscope, function generator, multimeter, and so forth. The research study on the students was done in two phases: Phase 1 and Phase 2. In Phase 1, an AR learning system was developed which aims to help the students to operate electronics laboratory hardware. Then participants of the two different groups were given different
teaching treatment using AR learning system and traditional teaching treatment. Then the effectiveness of AR learning system on student cognition and laboratory skills were measured.

In Phase 2, a modified version of AR learning system is developed depending on the opinions and criticism received from the users in Phase 1. Then the students of the treatment group were given the experience of the AR learning system version 2 and then the effectiveness of design changes of AR learning system on student cognition and laboratory skills were measured.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Measurement Variables</th>
<th>Type of Treatment</th>
<th>Test of Analysis</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>Laboratory Skills; Cognitive Load; Learning Motivation</td>
<td>Treatment Group (N=30) Treated with AR Learning System</td>
<td>Independent Sample t-test</td>
<td>Hypothesis 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control Group (N=30) Treated with Traditional teaching approach</td>
<td>Hypothesis 2</td>
<td>Hypothesis 3</td>
</tr>
<tr>
<td>Phase 2</td>
<td>Laboratory Skills; Cognitive Load;</td>
<td>Treatment Group (N=30) Treated with AR Learning System (version 2)</td>
<td>Wilcoxon signed rank test</td>
<td>Hypothesis 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hypothesis 5</td>
</tr>
</tbody>
</table>

3.5 Measurement Tools

The measurement tools utilized in this investigation incorporate pre and post-test for measuring laboratory skills, survey forms for assessing cognitive load and learning motivation of two groups who utilized two diverse approaches for learning about laboratory hardware.

3.5.1 Laboratory Skill Test

The laboratory skill assessment was aimed to gauge the laboratory skills of the students to operate oscilloscope and function generator. All respondents were
examined in the presence of the teacher to take the exam separately and they were asked to accomplish the specific task on the laboratory hardware. The laboratory skill test for Phase 1 and Phase 2 of the research study was different and the details of the test for two phases are given in subsequent sections. The rubrics for assessing the laboratory skills of students were planned by the faculty members having more than ten years of teaching experience in engineering education.

3.5.1.1 Laboratory Skill Test for Phase 1

In Phase 1 of research design, the students were directed to go through the laboratory skill test in pre and post-test design approach. Prior to the experiment, the pre-test was performed. After the pre-test, all the respondents took part in the experiment and then post-test was completed for the two groups. The test's highest total was 10 and details of rubrics are mentioned in Annexure A. The participants were inquired to carry out the subsequent assignments on the laboratory hardware amid the skill examination.

- Firstly, they were asked to make the connection between the output port of the function generator and the input port of oscilloscope.
- After that, they were required to generate the signal from function generator of specific amplitude and frequency.
- Now, they have to observe the signal on an oscilloscope by adjusting controls of the oscilloscope.
- In the last step, they have to measure the peak voltage and time-period of a signal on the oscilloscope.

3.5.1.2 Laboratory Skill Test for Phase 2

In Phase 2 of the research design, the criteria for measuring laboratory skills of the student was different from Phase 1. In laboratory skill test, students were asked to generate different signals with specific amplitude and frequency from the function generator. Also, they were inquired to gauge the signal parameters (like maximum voltage and signal frequency) of different signals on the oscilloscope. The assessment was intended to measure student’s expertise on both the hardware equipment separately. The assessment was focused on two parameters: skill test
score and time completion time. During the test, both the parameters (test scores and test completion time) for each laboratory equipment were recorded. After the test, the following parameters were recorded for each participant:

- Test score on the Function generator.
- Test score on Oscilloscope.
- Completion time to accomplish the exam on the Function generator.
- Completion time to accomplish the exam on Oscilloscope.

The details of the rubrics and scoring pattern of the laboratory skill test are mentioned in Annexure B.

### 3.5.2 Cognitive Load Questionnaire

Cognitive load questionnaire was planned to quantify cognitive load among the students during the learning activity about laboratory equipment. The questionnaire is a direct-subjective method to report stress and difficulty levels experienced by the students throughout the learning process. The survey was amended from the survey questionnaire designed by Hwang, Yang and Wang, (2013). The survey was centered on the parameters provided by Paas, 1992; Sweller, Van Merrienboer and Paas, (1998). It comprises of eight things: five things for ‘Mental Load’ and three things for ‘Mental Effort’. It consists of things like “The learning content in this learning activity was difficult for me”, “I had to put a lot of effort into answering the questions in this learning activity”, “I need to put lots of effort into completing the learning tasks or achieving the learning objectives in this learning activity”. The students reacted on a five-point Likert scale. The Cronbach’s alpha values of Mental load and Mental effort in the study by Hwang, Yang and Wang, (2013) were 0.86 and 0.85 respectively. In the present work, the Cronbach’s alpha values for Mental load is 0.81 and for Mental effort is 0.78 presenting high reliability of the survey. Chang and Hwang, (2018) successfully used the questionnaire to measure the cognitive load. The cognitive load questionnaire is given in Annexure C.
3.5.3 Learning Motivation Questionnaire

Learning motivation questionnaire is a multi-dimensional subjective assessment method that was envisioned to measure motivation among the students to learn about laboratory equipment. The survey was amended from the survey questions developed by Hwang, Yang and Wang, (2013). The survey comprises of six things and students have answered on five-point Likert scale. It consists of things such as “I think learning about laboratory equipment (Oscilloscope and function generator) is interesting and valuable”, “I would like to learn more and observe more in the electronics engineering laboratory course” etc. The Cronbach’s alpha values of learning motivation in the study by Hwang, Yang and Wang, (2013) was 0.79 and it is 0.71 in the present study which shows acceptable reliability of the survey. Hwang et al., (2016); Chang and Hwang, (2018) successfully used the questionnaire to measure the learning motivation. The learning motivation questionnaire is given in Annexure D.

3.6 Conduct of Experiment

3.6.1 Experiment Design for Phase 1

In this phase, all students were at first given a fundamental laboratory hardware lesson to get them to know the hardware devices. After the lesson, to assess the essential skills and comprehension of laboratory hardware participants were inquired to undergo the pre-test exclusively. In the test, participants were inquired to accomplish the test using the laboratory hardware. 15 minutes were given to students to finish the test.

After the pre-test, participants were scattered arbitrarily into two divisions: Treatment group and Control group. The participants of the treatment group were given the training to operate laboratory hardware by utilizing the AR learning system. While the control group was acquainted with the laboratory equipment by utilizing lab manuals. The learning exercise went on for 75 minutes for each section.
After the learning exercise, participants were advised to complete the post-test and fill the surveys related to cognitive load and learning motivation. In post-test, students were inquired to accomplish the experiment on laboratory hardware in the supervision of the lab instructor. The time given to perform the post-test was 15 minutes. After learning exercise, the participants of the treatment group were too inquired to provide their input about the AR learning system. This feedback helped in the modifying design framework of AR learning system (version 1). The experimental plan of the learning exercise for phase 1 is exhibited in Figure 3.2. Table 3.2 presents the measurement variables which are measured in the Phase 1 of the study.

<table>
<thead>
<tr>
<th>Measurement Variable</th>
<th>Instrument</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Laboratory Skills</td>
<td>Laboratory Skill Test - 1</td>
<td>This variable was used to benchmark participant’s laboratory skills to operate the equipment prior to the experiment. It will be used to compare the skills acquired after the instructional treatments.</td>
</tr>
<tr>
<td>Post Treatment Laboratory Skills</td>
<td>Laboratory Skill Test - 1</td>
<td>This variable was used to compare the laboratory skills of treatment group and control group after the instructional treatment.</td>
</tr>
<tr>
<td>Cognitive Load</td>
<td>Cognitive Load Questionnaire developed by Hwang, Yang and Wang, (2013)</td>
<td>This variable was used to measure the cognitive load caused by different learning approaches.</td>
</tr>
</tbody>
</table>
Learning Motivation Questionnaire developed by Hwang, Yang and Wang, (2013)

This variable was used to measure the learning motivation of the two groups who used different learning approaches: treatment group and control group.

<table>
<thead>
<tr>
<th>Learning Motivation</th>
<th>Dependent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning Motivation Questionnaire developed by Hwang, Yang and Wang, (2013)</td>
<td>This variable was used to measure the learning motivation of the two groups who used different learning approaches: treatment group and control group.</td>
</tr>
</tbody>
</table>

Fig. 3.2 Experimental Design for Phase 1

3.6.2 Experiment Design for Phase 2

In Phase 2, modifications based on the student feedback was done in AR learning system (version 1) and version 2 of AR learning system was developed. The details of the modifications are mentioned in section 4.4 of Chapter 4. Now, the participants of treatment group were given the experience of using the AR learning system (version 2) and the impact of design changes in AR learning system (version 2) on cognitive load and technical skills of students was measured. Figure 3.3 shows the experimental design of the learning exercise for phase 2 and Table 3.3 presents the measurement variables of Phase 2.
**Fig. 3.3 Experimental Design for Phase 2**

**TABLE 3.4 Measurement Variables of Phase 2**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Variable</th>
<th>Instrument</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Laboratory Skills on Function Generator</td>
<td>Independent</td>
<td>Laboratory Skill Test - 2</td>
<td>This variable was used to scale the participant’s laboratory skills to operate the function generator in engineering laboratory prior to the experiment. It will be used to compare the skills acquired after the instructional treatments.</td>
</tr>
<tr>
<td>Prior Laboratory Skills on Oscilloscope</td>
<td>Independent</td>
<td>Laboratory Skill Test - 2</td>
<td>This variable was used to scale the participant’s laboratory skills to operate oscilloscope in engineering laboratory prior to the experiment. It will be used to compare the skills</td>
</tr>
</tbody>
</table>
acquired after the instructional treatments.

<table>
<thead>
<tr>
<th>Post Treatment</th>
<th>Laboratory Skills on Function Generator</th>
<th>Laboratory Skill Test - 2</th>
<th>This variable was used to compare the laboratory skills on function generator after the instructional treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Treatment</td>
<td>Laboratory Skills on Oscilloscope</td>
<td>Laboratory Skill Test - 2</td>
<td>This variable was used to compare the laboratory skills on oscilloscope after the instructional treatment.</td>
</tr>
<tr>
<td>Cognitive Load</td>
<td>Dependent</td>
<td>Cognitive Load Questionnaire developed by Hwang, Yang and Wang, (2013)</td>
<td>This variable was used to measure the cognitive load caused by different learning approaches.</td>
</tr>
</tbody>
</table>

3.7 Experimental Validity

Internal validity: One potential risk to the internal legitimacy of this research study is the sampling bias and attributes of the participants. It is not feasible to have a genuine random sample from the student population of the university and to experiment with whole students of the university. So, a comparatively small sample is selected for the study which may not accurately represent the larger student population. This may cause a methodical bias where the results of sampled populations differ from the results of the entire population. The sample size of 60 students is sufficient to apply the independent sample t-test and interpret the results. Although a bigger sample size could have provided better results. But in this study, an exploratory experiment was conducted to gauge the effectiveness of using AR in engineering labs specifically in electronics engineering. In the experiment, each student was asked to perform the specific tasks on oscilloscope and function generator. So it will be difficult to conduct these activities for the bigger sample
population. Moreover, measurement instruments are not affecting the internal validity of the study. The measurement tools that are used in this study are consistent in determining technical skills, cognitive load and learning motivation of the participants.

**External validity**: No threats to the external validity were found in this exploratory research design.

3.8 **Instructional Material**

This exploratory analysis anticipates determining the impression of AR mediation on student aptitudes and cognition in laboratory courses. The participants were disseminated into two groups who used two distinct training strategies. The students of the treatment group utilized AR learning system as a training tool for acquiring knowledge about laboratory hardware and control group students were trained through conventional teaching approach.

3.8.1 **AR Learning System**

The AR learning system was developed explicitly to benefit undergraduate engineering students to work on the function generator and oscilloscope in the laboratory. The developed AR learning system is an active learning tool which involves learner actively in the learning process. The developed AR system is centered on a marker tracking system which utilizes QR codes as markers for overlaying the 3D models of laboratory equipment. The students can interface with the 3D models of the laboratory hardware utilizing a PC mouse. By utilizing the mouse, students can press the switches and turn the knobs of the virtual hardware available in the AR environment. There is an information bar in the interface of AR learning system which gives the supplementary information about the significance of equipment buttons and knobs.
Fig. 3.4 User Interface of AR Learning System

Fig. 3.5 Participants of Treatment Group learning through AR Learning System in Engineering Laboratory
3.8.2 Laboratory Manual

The participants of the control group were instructed using traditional teaching methodology which utilizes laboratory manual as a learning tool. The laboratory manual has the sequence of procedure for operating the oscilloscope and function generator and it mainly consists of 2D images and textual instructions. The laboratory manual was prepared by the faculty members of the university who have expertise in the specified domain. The detailed procedure of the experiment is given in the following:

- Interface the output of function generator with Channel input of CRO using BNC-BNC cable and switch on the both equipment. The connection between CRO and function generator is given in Fig. 3.6.

![Fig. 3.6 Connection between Oscilloscope and Function Generator](image)

- Select the type of signal on the function generator to produce the wave. Now, set the frequency of the signal on function generator from the frequency knob.
- Now set the output voltage of the signal on function generator by turning the amplitude knob.
- On the oscilloscope, select the AC coupling and select Channel 1 as a source.
• For proper visualization of the signal on an oscilloscope, rotate the Time/Div. knob and Volts/Div. knob to adjust the signal amplitude and frequency respectively.
• Measure the time-period of the signal using the Eq. (2.1).

\[ \text{Time period, } t = X \times \text{Value of Time/Div. Knob} \] (2.1)

where \( X \) = Measurement of 1 cycle of a wave on the Oscilloscope screen

Calculate the frequency of signal, \( F\text{requency, } f = \frac{1}{\text{Time Period, } t} \)

• Calculate the Peak Voltage, \( V_p \) of the signal using the Eq. (2.2).

\[ \text{Peak Voltage, } V_p = \frac{1}{2} \times Y \times \text{Value of Volts/Div. Knob} \] (2.2)

where \( Y \) = Measurement of Peak to Peak amplitude of wave on Oscilloscope Screen

Fig. 3.7 Students of Control group learning through conventional teaching approach
3.9 Data Analysis Procedures

The quantitative data gathered during the experimental study was analyzed to examine the research hypothesis. The quantitative information comprises of pre and post-test scores of laboratory skills, cognitive load scores and learning motivation scores from the survey questionnaires. To analyze the quantitative data, the following test was performed in SPSS software tool.

3.9.1 Independent Sample t-test

Independent sample t-test is utilized to examine the statistical difference between the means of two independent sections. It can compare the mean values of the two groups. In this study, t-test was utilized to examine the difference in the laboratory skills, cognitive load and learning motivation of the two groups during Phase 1 of the research design. The null hypothesis (H₀) of the t-test can be stated as:

H₀ : μ₁ = μ₂ (The population mean values of two groups are equal)

Where μ₁ and μ₂ are the population mean of the two independent groups.

The test statistic t for independent sample t-test is dependent upon whether equal variances among the two groups are assumed or not.

Case 1: When equal variances are assumed, the test statistic t can be expressed by Eq. (2.3)

\[ t = \frac{\bar{x}_1 - \bar{x}_2}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \] (2.3)

\[ s_p = \sqrt{\frac{(n_1 - 1) s_1^2 + (n_2 - 1) s_2^2}{n_1 + n_2 - 2}} \] (2.4)

The degree of freedom can be expressed by Eq. (2.5).

\[ df = n_1 + n_2 - 2 \] (2.5)

Case 2: When equal variances are not assumed, the test statistic t can be expressed by Eq. (2.6)
\[ t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \]  

(2.6)

The degree of freedom can be expressed by Eq. (2.7).

\[ df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{1}{n_1 - 1} \left(\frac{s_1^2}{n_1}\right)^2 + \frac{1}{n_2 - 1} \left(\frac{s_2^2}{n_2}\right)^2} \]  

(2.7)

Where \( \bar{x}_1 \) = Mean value of Group 1,

\( \bar{x}_2 \) = Mean value of Group 2,

\( n_1 \) = Sample size of Group 1,

\( n_2 \) = Sample size of Group 2,

\( s_1 \) = Standard deviation of Group 1,

\( s_2 \) = Standard deviation of Group 2,

\( s_p \) = Pooled Standard deviation

In both cases, the calculated t-value is compared with critical t-value from the distribution table and the confidence interval. The null hypothesis (H_0) can be rejected if the calculated t-value is greater than the critical t-value.

### 3.9.2 Wilcoxon Signed Rank Test

Wilcoxon signed rank test is a non-parametric test which is utilized to equate the scores of the same group at two distinctive occasions of intercession and it is utilized when the data is not supposed to be normally distributed. In this study, Wilcoxon signed rank test was used to compare the laboratory skills and cognitive load scores of treatment group through the Phase 2 of the experimentation. The null hypothesis (H_0) of the Wilcoxon signed rank test can be stated as:

H_0: The difference between the paired sample follows symmetric distribution around zero.
The test statistic $W$ for Wilcoxon signed rank test can be expressed by Eq. (2.8):

$$W = \sum_{i=1}^{N_r} [sgn(x_{2,i} - x_{1,i}) R_i]$$

(2.8)

Where, $N_r = \text{Number of pairs}$

$R_i = \text{Rank of pair}$

If the value of $|W| > W_{critical,N_r}$ then null hypothesis ($H_0$) can be rejected.
Chapter 4
Development of Augmented Reality Learning System

The primary objective of this study was to create an Augmented Reality learning system for undergraduate engineering students and analyze its effectiveness on laboratory skills and cognitive load. This chapter explains the development process of Augmented Reality Learning System. The AR learning framework was created to assist students in effective functioning of electronics laboratory hardware equipment. The developed learning system was an active learning tool which engages student in the learning progression. In order to develop the AR learning system, the following process as mentioned in Fig. 4.1 was followed.

4.1 Ideation

In engineering education, laboratories play an imperative part in developing and validating the concepts. Hands-on laboratory experience is viable in structuring and directing investigations which improves specialized lab aptitudes in building graduates (Bonislawski & Holub, 2018; Fraile-Ardanuy, Garcia-Gutierrez, Gordillo-Iracheta, & Maroto-Reques, 2011). The hands-on laboratory experience
demands high mental effort and cognitive load as the student need to manage advanced lab programming and equipment hardware (Alexiadis & Mitianoudis, 2013; Angulo, Rodriguez-Gil, & Garcia-Zubia, 2018; Odeh, Abu Shanab, Anabtawi, & Hodrob, 2013). In electrical and electronics engineering laboratories, function generator and oscilloscope were the most often used laboratory equipment. Nearly each electrical and electronics engineer has utilized this equipment amid their undergraduate course. An oscilloscope is an electronic test bench equipment which is utilized to observe time varied electrical signal on a two-dimensional plot. An oscilloscope is also utilized to calculate waveform parameters such as frequency, amplitude, time-period, etc. A function generator is electronic test equipment which is utilized to produce various kinds of electrical waveforms like a sinusoidal wave, square wave, or triangular wave. However, while working with this hardware equipment, it was troublesome for engineering students to work without any prior knowledge of the equipment (Chien, Tsai, Chen, Chang, & Chen, 2015; Chiu et al., 2015). Thus, this gives an opportunity to ease down the laboratory learning experience with the assistance of AR intervention (Wu, Lee, Chang, & Liang, 2013). In this research study, a learning environment based on AR was developed to help engineering graduates in operating oscilloscope and function generator.

The developed AR learning system was focused on the three design aspects as mentioned in Fig. 4.2: Technology aspects, Pedagogy aspects and Learner aspects. Technology aspects support the instructional design with technological design. The instructional design of the learning environment was supported by AR technological design which provides unique learning experiences to the students (Joaquín Cubillo, Martin, Castro, & Boticki, 2015; Hung, Chen, & Huang, 2017). Learner aspects deal with the student attention to accomplish lab aptitudes and acquire knowledge about laboratory hardware. The pedagogy aspect ensures that the content design of the learning environment is focused on learning objectives and learner-centered approach.

The AR learning system was based on a learner-centered approach in which learning activities were more centric towards student interest. In the learner-centered approach, the student is dynamically involved in the learning procedure.
which puts a more obligation on students (Klopfer & Squire, 2008; Stechert, 2006).
In the learner-centered approach, students were given more importance and responsibility of the learning while the role of a teacher is just as the facilitator (Forcheri, Molfino, & Quarati, 1998). The technological plan of AR learning system was bolstered by the instructional plan which keeps the learner’s autonomy (Fokides & Atsikpasi, 2018). The AR learning system enables the learner to work with the virtual replicas of laboratory hardware which gives them preceded experience and assurance to operate the hardware equipment.

Fig. 4.2 Design Aspects of AR Learning System

The AR learning system was centered around the accompanying learning goals:

- To empower the learners to produce various signal from the function generator.
- To empower the learners to visualize various signals on the oscilloscope.
- To empower the learners to utilize the oscilloscope for calculating time-period and voltage of various signals.

4.2 3D Modeling

The development of virtual content is very crucial in AR because it depicts the replica of real objects which directly affects the student experience, motivation and
usefulness of the system (Alexiou & Schippers, 2018; Aydogan & Aras, 2019; Dinet & Kitajima, 2018; Huang, Chen, & Lin, 2019; Yilmaz, 2016). So, the virtual content must be developed very precisely and accurately. In this section, the development process of 3D models of laboratory equipment like Oscilloscope and Function Generator are discussed. These custom built 3D models were further used to develop AR learning system to be used in this study. The 3D models of laboratory hardware were created utilizing Autodesk Maya which is animation and modeling tool utilized for creating virtual graphics and illustrations. In order to design the virtual replicas of laboratory hardware, the following steps as mentioned in Fig. 4.3 were considered.

![Fig. 4.3 Steps for 3D Model Development for AR Learning System](image)

### 4.2.1 Pre-Modeling

Pre-modeling starts before the modeling process. In this step, the survey of actual physical objects was done. In the survey, pictures and videos of real laboratory equipment from all viewing angles was gathered as a source of perspective. These reference images and videos helps in checking the accuracy of 3D models throughout the development process. In pre-modeling, a study related to object shapes and functioning of the equipment was done which helps the designer to develop the 3D models.
Fig. 4.4 Reference images of Oscilloscope from different viewpoints

Fig. 4.5 Reference images of Function generator from different viewpoints
As a reference, Scientech (ST-251) 25 MHz, 2 Channel, 4 trace Oscilloscope and Scientech (ST4060) 1 MHz Function Generator was selected for developing 3D models of laboratory equipment. Fig. 4.4 presents the reference pictures of oscilloscope from different viewpoints and Fig. 4.5 presents the reference pictures of function generator from different viewpoints.

4.2.2 Modeling

3D models characterize physical objects and comprises of a combination of points in 3D space which are further associated by geometric elements such as lines, triangles, bended surfaces, etc. The method of creating a mathematical and wireframe representation of a 3D object is known as modeling. A model is represented as a triangle mesh with vertices, faces, and edges, that characterizes the shape of a 3D object in computer graphics. Modeling begins with the essential shapes like cubes, cylinders, and spheres then meshes are added in such a way to induce the required shape of the 3D object (Dere, Sahasrabudhe, & Iyer, 2010). The working of 3D models was checked frequently in which fixed and movable parts were tested with boundary limits. Also, rendering test was done at significant steps to test the accuracy and precision of 3D models. The animations were also added to the buttons and knobs of 3D models of hardware equipment to bring interactivity. Linear movements were added to buttons of the 3D model, which could be used for button press function and rotational movements were added to the knobs of models which could be used to rotate the knob during gameplay. During the 3D modeling, a mesh may contain a high number of vertices and faces, which results in large file size and long rendering time. In order to keep rendering time low, mesh optimization technique was utilized. Mesh optimization is the process of removing all undesired vertices and edges that don’t affect the shape of the model (Hoppe, DeRose, Duchamp, McDonald, & Stuetzle, 1993; Sumner & Popović, 2004). Hence, by using mesh optimization during the 3D model development, the graphics performance was enhanced during rendering. Fig. 4.6 presents the wireframe images of 3D model of oscilloscope.
4.2.3 Texturing

Texturing is the process of applying 2D images on the outer surface of the 3D models. Texturing aims to define the surface texture and color details of 3D models. Proper textures are required to specify the properties of objects which bring realism in the 3D model (Huang et al., 2019). In this study, Adobe Photoshop software was used to generate the textures of the equipment and texturing was done post the modeling process. Fig. 4.7 presents the textures developed in Adobe Photoshop for 3D model of the oscilloscope. Fig. 4.8 presents the oscilloscope model without the textures and Fig. 4.9 presents the oscilloscope model with textures.
Fig. 4.7 Bitmap image used as texture for Oscilloscope Model

Fig. 4.8 Oscilloscope Model without textures
4.2.4 Lighting, Animation and Rendering Test

Lighting refers to the use of lights to provide aesthetic effects to the 3D models. In this step, light sources, intensity, and color of light are defined. Lights are essential in order to visualize the 3D models during rendering. In this study, global illumination was used as lighting technique. After lighting, the animation was the next step, the animation is the method of including movement to the static 3D models. In this step, linear movements were added to the buttons of 3D models of laboratory equipment and rotational movements were added to the knobs of 3D models. Finally, rendered images were extracted from the Autodesk Maya software. Rendered images of 3D models were presented in Fig. 4.10 and Fig. 4.11. After
rendering, the 3D models were imported to Unity 3D game engine for the development of AR learning system.

Fig. 4.10 Rendered images of Oscilloscope from Autodesk Maya

Fig. 4.11 Rendered image of Oscilloscope and Function generator from Autodesk Maya

4.3 AR Development

4.3.1 Development of Game Objects

Game objects are the essential entities that characterize various objects in a game. Game objects represent characters, items, and objects that are used in the game.
However, we need to define the properties and functionalities of the game objects (Cuendet, Bonnard, Do-Lenh, & Dillenbourg, 2013; de la Torre, Guinaldo, Heradio, & Dormido, 2015). Every game objects consist of components which define the physical and behavioral characteristics of game object during the gameplay (Rodriguez-Gil et al., 2017). The 3D virtual replicas of Oscilloscope and Function Generator that was designed in Autodesk Maya were imported to Unity 3D as game objects. In this study, various signal waves like a sine wave, triangular wave, and square wave were designed to be used as game objects. The waveforms were designed in Unity 3D game engine (“Unity Real-Time Development Platform | 3D, 2D VR & AR Visualizations,”) using the Vectrosity tool (“Vectrosity - Asset Store,”). Vectrosity is a toolset which is used for line-rendering in Unity. The three waveforms (sine, square and triangular) were designed as a mathematical function of amplitude and frequency. The waveforms were designed and overlaid on the model of Oscilloscope as shown in Fig. 4.12.

4.3.2 Scripting the Gameplay

In AR gameplay, the game objects are controlled by the scripts. Scripts fundamentally define the actions of game objects in the gameplay. In AR learning system, control scripts were added for switches and knobs of 3D models of laboratory hardware. The control script was written in C# language using the Unity editor. While pressing the specific switch of 3D model of function generator, waveforms (like sine, square and triangular wave) were created on the 3D model of the oscilloscope. User Interface (UI) was designed for the AR environment, keeping in mind that the student can perform actions on the virtual models of Oscilloscope and Function Generator using the computer mouse. The student can press the button of the 3D model of equipment using left mouse click function and can rotate the knob of equipment using mouse scroll function. In AR simulation, the student can vary the frequency and amplitude of the wave by turning the appropriate knobs of the function generator. Also, student can adjust the signal voltage and time-period on the oscilloscope by utilizing relevant knobs and buttons.
Fig. 4.12 (a) Sine wave is designed as Game Object, (b) Square wave is designed as Game Object, (c) Triangular wave is designed as Game Object
There is also an information bar provided on the screen, which exhibits information regarding significance of buttons and knobs of equipment. Information bar helps the student in understanding and operating the equipment. Whenever learner points the cursor of the mouse on a certain button or knob, the information bar displays the information related to the utility of the button/knob of oscilloscope and function generator. In this way, AR learning system provided better visualization to the learner and it becomes easier to operate the equipment. Fig. 4.13 presents the UI of the AR application.

![Image](image_url)

Fig. 4.13 User Interface of AR application

4.3.3 AR Application

The developed AR application uses marker-based tracking for overlaying the virtual models of laboratory hardware equipment. In this study, QR codes were used as markers as displayed in Figure 4.14. The AR application was developed for the table-top environment on Windows-based desktop platform. The application was designed by using EasyAR software tool which helps in tracking for AR application (Nguyen & Dang, 2017; Prit Kaur, Mantri, & Horan, 2018). EasyAR is an AR-SDK available for smartphones and PC platform, which employs computer vision techniques to track the target object for overlaying virtual content. The developed AR application used multiple marker tracking techniques for overlaying the virtual...
models of laboratory hardware equipment. Fig. 4.15 shows the AR setup for Oscilloscope and Function Generator in Electronics Engineering laboratory.

![AR setup for Oscilloscope and Function Generator in Electronics Engineering laboratory](image)

**Fig. 4.15** AR setup for Oscilloscope and Function Generator in Electronics Engineering Laboratory

### 4.4 Development of AR Learning System version 2

The AR learning system was deployed on the engineering students and they were moreover satisfied with the experience of utilizing the AR in the engineering
laboratory. However, they proposed a few advancements which can be further added to improve the AR experience. The following improvements were suggested by the users who utilized AR learning system:

- Instructional tutorial related to the laboratory hardware can be included which may enhance clarity and ease of use of AR framework.
- The functionality of the laboratory hardware equipment in AR framework needs to be more realistic. More functions of laboratory equipment can be added.
- User interface and graphics can be improved.

After receiving the feedback of the students, the design framework of AR learning system version 2 was planned and the development was completed. The following features were included in version 2 of AR learning system:

- The tutorial related to laboratory equipment was added to the AR learning system.
- The values of frequency and amplitude are displayed on the function generator display.
- The buttons related to frequency range selection on function generator are now operational in AR learning system.
- The student can select the Channel on the oscilloscope. Channel 1 and Channel 2 both are enabled now.
- The UI of the AR learning system has been improved.
- Also, a real-time interface between oscilloscope and AR learning system was developed using Arduino as an interface.

The details of these features are described in the subsequent section.

4.4.1 Tutorial

While using version 1 of AR learning system, students found it difficult to operate the AR learning system as they were not aware of the process. To ease down the learning experience with AR, a tutorial related to laboratory equipment was included in version 2 of AR learning system. In the tutorial, text information and 2D images about the front panel of oscilloscope and function generator was used to
give brief information to the students. Figure 4.16 and 4.17 present the tutorial slides about oscilloscope and function generator respectively.

![Tutorial about front panel of Oscilloscope](image1)

**Fig. 4.16 Tutorial about front panel of Oscilloscope**

![Tutorial about front panel of Function Generator](image2)

**Fig. 4.17 Tutorial about front panel of Function Generator**

### 4.4.2 Modifications in functioning of 3D model of Function Generator and Oscilloscope

In version 1 of AR learning system, the values of amplitude and frequency of the signal generated were not displayed on the 3D model of the function generator.
In the feedback taken from students, they have mentioned explicitly that these values should be displayed on the function generator which will bring more reality into the 3D model. Also, there were frequency range selector buttons on the front panel of the function generator which was not functional in version 1 of AR learning system. The frequency range selector buttons are used to select the frequency range of the signal to be generated. Now in version 2 of AR learning system, frequency range selector buttons were made functional so, that student can select the frequency range and generate a signal of a particular frequency. Figure 4.18 and 4.19 shows the changes in the 3D model of the function generator.

The oscilloscope has 2 channels (named as Channel 1 and Channel 2), each channel is used to connect the signal and display it onto the oscilloscope screen. The student can select the channel by pressing the Channel selection button. In version 1 of AR learning system, the student did not have the flexibility of selecting a different channel of the oscilloscope as only one channel was functional. Now, both the channels of oscilloscope were made functional in version 2 of AR learning system. Figure 4.20 shows the different channels selected at different time by the student in AR learning system version 2. The above-mentioned points were considered during the development of version 2 of AR learning system.

Fig. 4.18 Modifications in 3D model of Function generator
4.4.3 Integrating Arduino interface with AR Learning System

In this step, a real-time interface between real oscilloscope and AR learning system was developed using Arduino as an interface. To develop the interface, an extension of Unity 3D game engine named Uniduino was used. Uniduino enables Unity 3D to connect with Arduino board and read the real-time analog and digital.
values from any electronic circuit. In version 2 of AR learning system, the connection between the real oscilloscope and ARLE was established using Uniduino and Arduino board. The Arduino board was used to read the real-time changes in the values of amplitude and frequency when the Time/Div. knob and Volts/Div. knob of the real oscilloscope was rotated. The Arduino board passes these values to Uniduino and then Unity 3D processes these values and make changes in the signal waveforms in the AR environment. The block diagram of the interface is shown in Figure 4.21. When the student rotates the knobs of amplitude control and frequency control on the real oscilloscope, the voltage level changes in the control circuit of the oscilloscope. So, the real-time values from the amplitude control circuit and the frequency control circuit (time base generator) of oscilloscope were read with the help of Arduino board. The Uniduino extension passes these values to the Unity game engine. The control script was added which changes the amplitude and frequency of waveform in the learning environment with respect to the real-time values from the amplitude control circuit and the frequency control circuit of the oscilloscope. This real-time system would enhance student visualization and understanding. Figure 4.22 shows the AR learning system version 2 setup in the engineering laboratory.

![Block Diagram of Arduino interface with Unity 3D](image)

**Fig. 4.21 Block Diagram of Arduino interface with Unity 3D**
Fig. 4.22 AR Learning System (version 2) setup in Engineering Laboratory
Chapter 5

Results and Discussion

This chapter provides the evaluation of the data and hypothesis testing carried out in this research. During the experiment in the engineering laboratory, the information was gathered from the students. The analysis of information is provided as descriptive statistics and statistical inferential analysis. The information was analyzed using the SPSS statistical.

5.1 Descriptive Statistics

5.1.1 Descriptive of Laboratory Skill test for Phase 1

The purpose of the laboratory skill test was to calculate the influence of instructional treatment on laboratory skill of students. The pre and post-test design approach was utilized for laboratory skill test. The descriptive statistics of laboratory skill test for Phase 1 of experiment design are presented in Table 5.1, 5.2 and 5.3. The mean value of pre-test score for the treatment group was 1.0 with a SD of 1.14 and the mean pre-test score for control group is 1.43 with a SD of 1.33. The values of skewness and kurtosis for both pre and post-test are within the suitable range of ±1.96 so the distribution is normal (George & Mallery, 2003). Figure 5.1 and 5.2 presents the normal distribution curve for the pre-test and post-test scores respectively. Figure 5.3 and 5.4 presents the group wise box plots for pre-test and post-test scores respectively.

Table 5.1: Case Processing Summary for Pre and Post Laboratory Skill test

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<tr>
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<th></th>
<th>Excluded</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Percent</td>
<td>N</td>
<td>Percent</td>
<td>N</td>
<td>Percent</td>
</tr>
<tr>
<td>Pre-Test</td>
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<td>0</td>
<td>0.0%</td>
<td>60</td>
<td>100.0%</td>
</tr>
<tr>
<td>Group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-Test</td>
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<td>0.0%</td>
<td>60</td>
<td>100.0%</td>
</tr>
<tr>
<td>Group</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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</tbody>
</table>
### Table 5.2: Descriptive Statistics of Pre-test

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<tr>
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<th>Statistics</th>
<th>Treatment Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
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<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td>1.000</td>
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<td>Std. Deviation</td>
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</tr>
<tr>
<td></td>
<td>Minimum</td>
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<td>5.00</td>
<td>5.00</td>
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<td>Skewness</td>
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<td>0.920</td>
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<td>Std. Error of Skewness</td>
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<td>0.427</td>
<td>0.309</td>
</tr>
<tr>
<td></td>
<td>Kurtosis</td>
<td>-0.027</td>
<td>0.312</td>
<td>0.285</td>
</tr>
<tr>
<td></td>
<td>Std. Error of Kurtosis</td>
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</table>

### Table 5.3: Descriptive Statistics of Post-test

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<th>Control Group</th>
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</tr>
</thead>
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<td></td>
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<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>30</td>
<td>60</td>
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<td>Mean</td>
<td>8.166</td>
<td>4.900</td>
<td>6.533</td>
</tr>
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<td></td>
<td>Median</td>
<td>8.500</td>
<td>4.000</td>
<td>7.000</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
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<td>2.733</td>
<td>2.919</td>
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<td></td>
<td>Minimum</td>
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<td>0.000</td>
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<td></td>
<td>Maximum</td>
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<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td>Skewness</td>
<td>-0.872</td>
<td>0.199</td>
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</tr>
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<td></td>
<td>Std. Error of Skewness</td>
<td>0.427</td>
<td>0.427</td>
<td>0.309</td>
</tr>
<tr>
<td></td>
<td>Kurtosis</td>
<td>-0.467</td>
<td>-0.760</td>
<td>-0.972</td>
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<td></td>
<td>Std. Error of Kurtosis</td>
<td>0.833</td>
<td>0.833</td>
<td>0.608</td>
</tr>
</tbody>
</table>
Fig. 5.1 Distribution of Pre-test scores for total sample

Fig. 5.2 Distribution of Post-test scores for total sample
Fig. 5.3 Group wise Box plots of Pre-test scores

Fig. 5.4 Group wise Box plots of Post-test scores
5.1.2 Descriptive of Cognitive Load questionnaire for Phase 1

The questionnaire on cognitive load was utilized to calculate the cognitive load observed by students during the experiment. The descriptive statistics of cognitive load questionnaire for Phase 1 of experiment design are presented in Table 5.4 and 5.5. The mean score for treatment group cognitive load is 1.64 with a SD of 0.44 and the mean score of control group cognitive load is 2.03 with a SD of 0.83. The values of skewness and kurtosis for cognitive load are within the acceptable range of ±1.96 so the distribution is normal (George & Mallery, 2003). Figure 5.5 presents the normal distribution curve of cognitive load questionnaire for the total sample. Figure 5.6 presents the group wise box plots for cognitive load questionnaire.

Table 5.4: Case Processing Summary for Cognitive Load questionnaire

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<th>Cases</th>
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<th>Excluded</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Percent</td>
<td>N</td>
<td>Percent</td>
</tr>
<tr>
<td>60</td>
<td>100.0%</td>
<td>0</td>
<td>0.0%</td>
</tr>
<tr>
<td>60</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.5: Descriptive Statistics of Cognitive Load questionnaire

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<th>Statistics</th>
<th>Treatment Group</th>
<th>Control Group</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Load</td>
<td>N</td>
<td>30</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1.641</td>
<td>2.033</td>
<td>1.837</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>1.562</td>
<td>1.812</td>
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<td>Std. Deviation</td>
<td>0.442</td>
<td>0.834</td>
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<tr>
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<td>Minimum</td>
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<td>2.50</td>
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<td>3.88</td>
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<td>Skewness</td>
<td>0.367</td>
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<td>Std. Error of Skewness</td>
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<td>0.427</td>
<td>0.309</td>
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<tr>
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<td>Kurtosis</td>
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<td>0.090</td>
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<tr>
<td></td>
<td>Std. Error of Kurtosis</td>
<td>0.833</td>
<td>0.833</td>
<td>0.608</td>
</tr>
</tbody>
</table>
Fig. 5.5 Distribution of responses of Cognitive Load questionnaire for total sample

![Histogram of Cognitive Load](image1)

Mean = 1.2375
Std. Dev = 0.3058
N = 50

Fig. 5.6 Group wise Box plots of responses of Cognitive Load questionnaire

![Box plots of Cognitive Load](image2)

![Box plots of Cognitive Load](image3)
5.1.3 Descriptive of Learning Motivation questionnaire for Phase 1

The learning motivation questionnaire was utilized to evaluate student’s learning motivation during the learning process. The descriptive statistics of learning motivation questionnaire for Phase 1 of experiment design are presented in Table 5.6 and 5.7. The mean score for treatment group learning motivation is 4.46 with a SD of 0.43 and the mean score for control group learning motivation is 4.31 with a SD of 0.44. The values of skewness and kurtosis for cognitive load are within the acceptable range of ±1.96 so the distribution is normal (George & Mallery, 2003). Figure 5.7 presents the normal distribution curve of learning motivation questionnaire for the total sample. Figure 5.8 presents the group wise box plots for learning motivation questionnaire.

Table 5.6: Case Processing Summary for Learning Motivation questionnaire

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<th>Cases</th>
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</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Percent</td>
<td>N</td>
<td>Percent</td>
</tr>
<tr>
<td>Learning Motivation Group</td>
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<td></td>
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</tbody>
</table>

Table 5.7: Descriptive Statistics of Learning Motivation questionnaire

<table>
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<th>Variable</th>
<th>Statistics</th>
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<th>Control Group</th>
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</tr>
</thead>
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<td>Learning Motivation</td>
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<td>30</td>
<td>60</td>
</tr>
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<td>Mean</td>
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<td>4.311</td>
<td>4.386</td>
<td></td>
</tr>
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<td>Median</td>
<td>4.500</td>
<td>4.250</td>
<td>4.333</td>
<td></td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>0.434</td>
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<td>0.444</td>
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<td>Minimum</td>
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<td>3.50</td>
<td>3.50</td>
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</tr>
<tr>
<td>Maximum</td>
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<td>5.00</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
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<td>0.095</td>
<td>-0.308</td>
<td></td>
</tr>
<tr>
<td>Std. Error of Skewness</td>
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<td>0.427</td>
<td>0.309</td>
<td></td>
</tr>
<tr>
<td>Kurtosis</td>
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<td>-1.046</td>
<td>-0.929</td>
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</tr>
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<td>Std. Error of Kurtosis</td>
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<td>0.833</td>
<td>0.608</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5.7 Distribution of responses of Learning Motivation questionnaire for total sample

Fig. 5.8 Group wise Box plots of responses of Learning Motivation questionnaire
5.1.4 Descriptive of Laboratory Skill test for Phase 2

In Phase 2 of the experiment design, the laboratory skill test was designed to individually evaluate the expertise of student expertise on both the hardware equipment. The test was focused on two parameters: skill test score and test completion time. During the test, both the parameters (skill test scores and test completion time) for each laboratory equipment were recorded for each participant. The descriptive statistics of laboratory skill test for Phase 2 of experiment design are presented in Table 5.8, 5.9 and 5.10. The values of skewness and kurtosis for pre-test are within the acceptable range of ±1.96 so the distribution is normal (George & Mallery, 2003). Figure 5.9 shows the distribution of pre-test scores of treatment group and Figure 5.10 shows the distribution of time taken to complete the pre-test by treatment group students. For the post-test, the values of skewness and kurtosis are beyond the suitable range of ±1.96 so the distribution of data is not normal. Figure 5.11 shows the distribution of post-test scores of treatment group and Figure 5.12 shows the distribution of time taken to complete the post-test by treatment group students.

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<th>Pre-Test Scores on Function Generator</th>
<th>Pre-Test Time on Function Generator</th>
<th>Pre-Test Scores on Oscilloscope</th>
<th>Pre-Test Time on Oscilloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
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<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Mean</td>
<td>9.033</td>
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<td>2.166</td>
<td>0:13:59</td>
</tr>
<tr>
<td>Median</td>
<td>10.000</td>
<td>0:10:30</td>
<td>0.500</td>
<td>0:15:18</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>2.941</td>
<td>0:02:50</td>
<td>2.653</td>
<td>0:04:17</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.00</td>
<td>0:04:47</td>
<td>0.00</td>
<td>0:07:20</td>
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</table>

Table 5.8: Case Processing Summary for Pre and Post Laboratory Skill test

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<td></td>
<td>N</td>
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<td>N</td>
</tr>
<tr>
<td>Pre-Test</td>
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<td>0</td>
</tr>
<tr>
<td>Post-Test</td>
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<td>100.0%</td>
<td>0</td>
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</table>

Table 5.9: Descriptive Statistics of Pre-test for each Laboratory Equipment
<table>
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<tr>
<th>Statistics</th>
<th>Post-Test Scores on Function Generator</th>
<th>Post Test Time on Function Generator</th>
<th>Post-Test Scores on Oscilloscope</th>
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</tr>
</thead>
<tbody>
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<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
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<td>11.066</td>
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</tr>
<tr>
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<td>12.000</td>
<td>0:09:24</td>
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<td>2.016</td>
<td>0:02:10</td>
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<tr>
<td>Minimum</td>
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<td>0:01:00</td>
<td>6.00</td>
<td>0:06:10</td>
</tr>
<tr>
<td>Maximum</td>
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<td>12.00</td>
<td>0:13:48</td>
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<td>-1.937</td>
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</tr>
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<td>0.427</td>
<td>0.427</td>
<td>0.427</td>
</tr>
<tr>
<td>Kurtosis</td>
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</tr>
<tr>
<td>Std. Error of Kurtosis</td>
<td>0.833</td>
<td>0.833</td>
<td>0.833</td>
<td>0.833</td>
</tr>
</tbody>
</table>

Table 5.10: Descriptive Statistics of Post-test for each Laboratory Equipment
Fig. 5.9 (a) Distribution of Pre-test score on Function generator for treatment group; (b) Distribution of Pre-test score on Oscilloscope for treatment group

Fig. 5.10 (a) Distribution of time to complete Pre-test on Function generator for treatment group; (b) Distribution of time to complete Pre-test on Oscilloscope for treatment group
Fig. 5.11 (a) Distribution of Post-test score on Function generator for treatment group; (b) Distribution of Post-test score on Oscilloscope for treatment group

Fig. 5.12 (a) Distribution of time to complete Post-test on Function generator for treatment group; (b) Distribution of time to complete Post-test on Oscilloscope for treatment group
5.1.5 Descriptive of Cognitive Load questionnaire for Phase 2

The descriptive statistics of cognitive load questionnaire for Phase 2 of experiment design are presented in Table 5.11 and 5.12. The value of kurtosis for cognitive load are beyond the acceptable range of ±1.96 so the distribution of data is not normal (George & Mallery, 2003). Figure 5.13 shows the distribution of responses of cognitive load questionnaire of treatment group in Phase 2.

Table 5.11: Case Processing Summary for Cognitive Load questionnaire

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<th></th>
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<td>Included</td>
<td>Excluded</td>
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<td></td>
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<tr>
<td>N</td>
<td>30</td>
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<td>30</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 5.12: Descriptive Statistics of Cognitive Load questionnaire

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<tr>
<th>Variable</th>
<th>Statistics</th>
<th>Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Load</td>
<td>N</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1.462</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>1.375</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>0.450</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Skewness</td>
<td>1.499</td>
</tr>
<tr>
<td></td>
<td>Std. Error of Skewness</td>
<td>0.427</td>
</tr>
<tr>
<td></td>
<td>Kurtosis</td>
<td>3.251</td>
</tr>
<tr>
<td></td>
<td>Std. Error of Kurtosis</td>
<td>0.833</td>
</tr>
</tbody>
</table>
5.2 Hypothesis Testing

The research study hypothesis will be evaluated in this section by employing independent sample t-test and Wilcoxon signed rank test.

Hypothesis 1: There will be no significant difference in the technical skills of students of AR treatment group and Traditional teaching group.

To find out the difference in laboratory skills of two treatment groups, the independent sample t-test was utilized to test the hypothesis. Initially, t-test was performed on the pre-test scores of both the groups to determine the difference in the student’s laboratory skills prior to the experimentation. Table 5.13 presents the group statistics for pre-test scores and Table 5.14 presents the t-test analysis for both the groups. The t-statistic for the test is -1.35 with a p-value > 0.05 which suggests that the mean values of pre-test scores for the two groups are not significantly different. Therefore, with 95 % confidence level, it was concluded that laboratory skills of the two groups prior to the experiment was similar. Now, the t-
test can be utilized to find out the difference in laboratory skills of the two treatment groups after the intervention.

After the experiment, independent sample t-test was utilized to measure the distinction in post-test scores of the two treatment groups. As presented in Table 5.15 and 5.16, the mean post-test score is 8.16 for treatment group and 4.90 for the control group with a p-value < 0.05 which suggest that the mean scores of post-test for the two treatment groups differs significantly. So based on the results, Hypothesis 1 can be rejected with 95 % confidence level and it can be concluded that AR mediation has a considerable beneficial effect on the student’s laboratory skills.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Test</td>
<td>Treatment Group</td>
<td>30</td>
<td>1.000</td>
<td>1.144</td>
<td>.208</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>30</td>
<td>1.433</td>
<td>1.330</td>
<td>.242</td>
</tr>
</tbody>
</table>

Table 5.13: Group Statistics of Pre-test scores for two groups

### Table 5.14: t-test analysis for Pre-test scores

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td>-.686</td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td>-1.352</td>
</tr>
</tbody>
</table>
Table 5.15: Group Statistics of Post-test scores for two groups

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-Test</td>
<td>Treatment Group</td>
<td>30</td>
<td>8.166</td>
<td>2.085</td>
<td>.380</td>
</tr>
<tr>
<td></td>
<td>Control Group</td>
<td>30</td>
<td>4.900</td>
<td>2.733</td>
<td>.499</td>
</tr>
</tbody>
</table>

Table 5.16: t-test analysis for Post-test scores

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Post-Test</td>
<td>Equal variances assumed</td>
<td>3.015</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.204</td>
<td>54.22</td>
<td>.000</td>
</tr>
</tbody>
</table>

Hypothesis 2: There will be no significant difference in the cognitive load of students of AR treatment group and Traditional teaching group.

To test this Hypothesis, the mean score of cognitive load for both the treatment groups were compared and independent sample t-test was deployed to analyse the statistical distinction between the two groups. As shown in Table 5.17 and 5.18, the mean value of cognitive load is 1.64 for treatment group and 2.03 for the control group with a p-value < 0.05 which suggests that the mean scores of the two groups is statistical different. It can therefore be concluded from the outcomes that the learners of the treatment group experienced less cognitive load than the learners of the control group during the experiment. So based on the findings, Hypothesis 2 can be rejected with 95% confidence level and it was found that AR intervention has a considerable beneficial impact on the students' cognitive load.
Cognitive load is measured on two parameters: mental load and mental effort. The mean value of mental load for treatment group is 1.68 and for control group is 2.06 which suggest that the students of treatment group observed less mental load when contrasted with the control group students. Also, the mean value of mental effort of treatment group is 1.57 and 1.97 for the control group which suggest that the students in the treatment group has to put less mental effort compared to the students in the control group. Figure 5.14 presents the mental-load and mental-effort comparison of the two groups.
Hypothesis 3: There will be no significant difference in the learning motivation of students of AR treatment group and Traditional teaching group.

To test this hypothesis, the mean scores of learning motivation for both the treatment groups was compared. An independent sample t-test was utilized to analyze the substantial difference between the mean scores of the two groups. As shown in Table 5.19 and 5.20, the mean value of learning motivation is 4.46 for the treatment group and 4.31 for control group with a p-value > 0.05 which suggests that the mean scores of the two treatment groups are not statistically different. So based on the findings, Hypothesis 3 is acceptable with a confidence level of 95 % and it is concluded that the learning motivation of students in the treatment group and the control group does not differ significantly.

Table 5.19: Group Statistics of Learning Motivation for two groups

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning</td>
<td>Treatment Group</td>
<td>30</td>
<td>4.461</td>
<td>0.434</td>
<td>0.079</td>
</tr>
<tr>
<td>Motivation</td>
<td>Control Group</td>
<td>30</td>
<td>4.311</td>
<td>0.447</td>
<td>0.081</td>
</tr>
</tbody>
</table>

Fig. 5.14 Comparison of Mental-load and Mental-effort for the two groups
Hypothesis 4: There will be no significant difference in the technical skills of students of AR treatment group when the design framework of AR Learning System will change.

Since the post-test scores of laboratory skill test in phase 2 are not normally distributed so this hypothesis was tested using the Wilcoxon Signed Ranks test. The Wilcoxon Signed Ranks test has been used to contrast the pre-test and post-test scores of the treatment group. Table 5.21 presents the descriptive statistics of pre-test and post-test for treatment group.

Table 5.22 presents the rank table of Wilcoxon signed rank test for pre-test and post-test. For pre-test score and post-test score on function generator, 18 participants have positive ranks which indicates that 18 students have scored higher in post-test compared to the pre-test of function generator. Also, 1 student have negative ranks which means that 1 student have scored lesser in post-test compared to pre-test. 11 students have ties which indicates that they have scored same in pre-test and post-test of function generator. Also, in terms of time to complete the test on function generator, all participants have negative ranks which suggests that all students have taken less time in completing the post-test as compared to pre-test.

Table 5.20: t-test analysis for Learning Motivation

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Levene's Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>Learning Motivation</td>
<td>0.073</td>
<td>.788</td>
</tr>
<tr>
<td></td>
<td>Equal variances assumed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equal variances not assumed</td>
<td></td>
</tr>
</tbody>
</table>

Hypothesis 4: There will be no significant difference in the technical skills of students of AR treatment group when the design framework of AR Learning System will change.

Since the post-test scores of laboratory skill test in phase 2 are not normally distributed so this hypothesis was tested using the Wilcoxon Signed Ranks test. The Wilcoxon Signed Ranks test has been used to contrast the pre-test and post-test scores of the treatment group. Table 5.21 presents the descriptive statistics of pre-test and post-test for treatment group.

Table 5.22 presents the rank table of Wilcoxon signed rank test for pre-test and post-test. For pre-test score and post-test score on function generator, 18 participants have positive ranks which indicates that 18 students have scored higher in post-test compared to the pre-test of function generator. Also, 1 student have negative ranks which means that 1 student have scored lesser in post-test compared to pre-test. 11 students have ties which indicates that they have scored same in pre-test and post-test of function generator. Also, in terms of time to complete the test on function generator, all participants have negative ranks which suggests that all students have taken less time in completing the post-test as compared to pre-test.
<table>
<thead>
<tr>
<th>Statistics</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Minim um</th>
<th>Maxim um</th>
<th>Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25th</td>
</tr>
<tr>
<td>Pre-Test Score on FG</td>
<td>30</td>
<td>9.033</td>
<td>2.941</td>
<td>2.00</td>
<td>12.00</td>
<td>6.000</td>
</tr>
<tr>
<td>Pre-Test Time on FG</td>
<td>30</td>
<td>0:10:26</td>
<td>0:02:50</td>
<td>0:04:47</td>
<td>0:16:54</td>
<td>0:08:08</td>
</tr>
<tr>
<td>Pre-Test Score on Oscilloscope</td>
<td>30</td>
<td>2.166</td>
<td>2.653</td>
<td>0.00</td>
<td>6.00</td>
<td>0.000</td>
</tr>
<tr>
<td>Pre-Test Time on Oscilloscope</td>
<td>30</td>
<td>0:13:59</td>
<td>0:04:17</td>
<td>0:07:20</td>
<td>0:20:30</td>
<td>0:09:41</td>
</tr>
<tr>
<td>Post-Test Score on FG</td>
<td>30</td>
<td>11.400</td>
<td>1.904</td>
<td>4.00</td>
<td>12.00</td>
<td>12.000</td>
</tr>
<tr>
<td>Post-Test Time on FG</td>
<td>30</td>
<td>0:04:31</td>
<td>0:01:33</td>
<td>0:01:00</td>
<td>0:08:24</td>
<td>0:03:28</td>
</tr>
<tr>
<td>Post-Test Score on Oscilloscope</td>
<td>30</td>
<td>11.066</td>
<td>2.016</td>
<td>6.00</td>
<td>12.00</td>
<td>12.000</td>
</tr>
<tr>
<td>Post-Test Time on Oscilloscope</td>
<td>30</td>
<td>0:09:30</td>
<td>0:02:10</td>
<td>0:06:10</td>
<td>0:13:48</td>
<td>0:07:31</td>
</tr>
</tbody>
</table>

During working with oscilloscope, 29 participants have positive ranks which indicates that 29 students have scored higher ranks in post-test related to pre-test of oscilloscope, and only 1 student have scored same score in both pre and post-test of oscilloscope. With regard to the time required to complete the oscilloscope test, as shown in Table 5.22, 26 participants have negative ranks which indicates that 26 students completed the post-test in less time compared to the pre-test. Also, 4 participants have positive ranks which indicates that 4 students took more time to complete the post-test compared to the pre-test on oscilloscope. As per the feedback taken from the teachers, the oscilloscope is difficult equipment to operate compared to function generator as they have to set the combination of knobs to observe the signal on the oscilloscope screen. That is why few students have still faced difficulties while operating the equipment.
Table 5.22: Rank Table of Wilcoxon Signed Rank Test for Pre-test and Post-test

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post_Test_Score_FG - Pre_Test_Score_FG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>1a</td>
<td>14.50</td>
<td>14.50</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>18b</td>
<td>9.75</td>
<td>175.50</td>
</tr>
<tr>
<td>Ties</td>
<td>11c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post_Test_Time_FG - Pre_Test_Time_FG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>30a</td>
<td>15.50</td>
<td>465.00</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>0a</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Ties</td>
<td>0f</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post_Test_Score_Oscilloscope - Pre_Test_Score_Oscilloscope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>0g</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>29b</td>
<td>15.00</td>
<td>435.00</td>
</tr>
<tr>
<td>Ties</td>
<td>1i</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post_Test_Time_Oscilloscope - Pre_Test_Time_Oscilloscope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative Ranks</td>
<td>26i</td>
<td>16.96</td>
<td>441.00</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>4k</td>
<td>6.00</td>
<td>24.00</td>
</tr>
<tr>
<td>Ties</td>
<td>0l</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- a. Post_Test_Score_FG < Pre_Test_Score_FG
- b. Post_Test_Score_FG > Pre_Test_Score_FG
- c. Post_Test_Score_FG = Pre_Test_Score_FG
- d. Post_Test_Time_FG < Pre_Test_Time_FG
- e. Post_Test_Time_FG > Pre_Test_Time_FG
- f. Post_Test_Time_FG = Pre_Test_Time_FG
- g. Post_Test_Score_Oscilloscope < Pre_Test_Score_Oscilloscope
- h. Post_Test_Score_Oscilloscope > Pre_Test_Score_Oscilloscope
- i. Post_Test_Score_Oscilloscope = Pre_Test_Score_Oscilloscope
- j. Post_Test_Time_Oscilloscope < Pre_Test_Time_Oscilloscope
- k. Post_Test_Time_Oscilloscope > Pre_Test_Time_Oscilloscope
- l. Post_Test_Time_Oscilloscope = Pre_Test_Time_Oscilloscope
As shown in Table 5.23, the p-value of Wilcoxon signed rank test for post-test scores is less than 0.05 for both function generator and oscilloscope. This indicates a substantial difference between the post-test scores and pre-test scores on function generator and oscilloscope. Also, the p-value of Wilcoxon signed rank test for post-test time is less than 0.05 which suggests a difference in time taken by students to complete the post-test and pre-test on function generator and oscilloscope. Hence, Hypothesis 4 can be rejected with 95% confidence level and it can be concluded that there is a substantial difference in the laboratory skills of the students when design framework of AR learning system was changed.

<table>
<thead>
<tr>
<th>Test Statistics of Wilcoxon Signed Rank Test for Pre-test and Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Post_Test_Score FG - Pre_Test_Score FG</strong></td>
</tr>
<tr>
<td>Z</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
</tr>
</tbody>
</table>

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.
c. Based on positive ranks.

**Hypothesis 5:** There will be no significant difference in the cognitive load of students of AR treatment group when the design framework of AR Learning System will change.

To test this hypothesis, the cognitive load of Phase 2 is compared with the cognitive load of Phase 1. Since, the distribution of cognitive load of Phase 2 is not normal so this hypothesis was tested using the Wilcoxon Signed Ranks test. Table 5.24 provides cognitive load descriptive statistics for treatment group.
As shown in Table 5.25, on Phase 2 of the experiment, out of 30 students, 15 students experienced less cognitive load compared to Phase 1, 7 students experienced more cognitive load compared to Phase 1, and 8 students experienced similar cognitive load in Phase 2 and Phase 1 of the experiment. As shown in Table 5.26, the p-value of Wilcoxon signed rank test for cognitive load is greater than 0.05 which suggests that there is no substantial difference in the cognitive load scores of Phase 1 and Phase 2 for treatment group. So, based on the findings, Hypothesis 5 is acceptable with a confidence level of 95% and it is concluded that there is no substantial difference in the student’s cognitive load when design framework of AR learning system was changed.

Table 5.24: Descriptive Statistics of Cognitive Load of Treatment Group

<table>
<thead>
<tr>
<th>Statistics</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>25th</th>
<th>50th (Median)</th>
<th>75th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1</td>
<td>30</td>
<td>1.641</td>
<td>0.442</td>
<td>1.00</td>
<td>2.50</td>
<td>1.343</td>
<td>1.562</td>
<td>2.000</td>
</tr>
<tr>
<td>Cognitive Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td>30</td>
<td>1.462</td>
<td>0.450</td>
<td>1.00</td>
<td>3.00</td>
<td>1.125</td>
<td>1.375</td>
<td>1.750</td>
</tr>
</tbody>
</table>

Table 5.25: Rank Table of Wilcoxon Signed Rank Test for Cognitive Load

<table>
<thead>
<tr>
<th>Cognitive Load Phase 2</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Ranks</td>
<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.03</td>
<td>180.50</td>
</tr>
<tr>
<td>Positive Ranks</td>
<td>7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.36</td>
<td>72.50</td>
</tr>
<tr>
<td>Ties</td>
<td>8&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Cognitive Load Phase 2 < Cognitive Load Phase 1  
<sup>b</sup> Cognitive Load Phase 2 > Cognitive Load Phase 1  
<sup>c</sup> Cognitive Load Phase 2 = Cognitive Load Phase 1
Table 5.2: Test Statistics of Wilcoxon Signed Rank Test for Cognitive Load

<table>
<thead>
<tr>
<th>Test Statistics</th>
<th>Cognitive Load Phase 2 - Cognitive Load Phase 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>-1.759&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Asymp. Sig. 2-tailed</td>
<td>0.079</td>
</tr>
</tbody>
</table>

a. Wilcoxon Signed Ranks Test  
b. Based on positive ranks

5.3 Discussion by Hypothesis

The subsequent discussion is centered on the research hypothesis of this study:

**Hypothesis 1: There will be no significant difference in the technical skills of students of AR treatment group and Traditional teaching group.**

After the experiment, the laboratory skills of the two treatment groups were measured using the post-test of laboratory skill test. The mean scores of laboratory skill test of both the groups were compared to determine the statistical difference between the groups. Statistical analysis stated that the laboratory skills of the two treatment groups differ significantly. The mean post-test score for the treatment group was 8.16 and 4.90 for the control group, which indicates that the treatment group students gained better laboratory expertise when matched with the control group students. One of the possible reason for the difference in post-test score could be the ability of treatment group students to function the laboratory hardware has enhanced after the AR intervention. It was observed during the post-test that control group students were not comfortable in operating the oscilloscope and committing errors in calculating the signal elements on the oscilloscope. However, they are operating function generator with ease. While the treatment group students were comfortably working on oscilloscope and function generator, due to which they performed better in post-test. With AR intervention, the interaction of students with laboratory equipment has enhanced as AR content enables the student to understand the meaning of the equipment's buttons and knobs. The AR intervention enhanced the ability of the student to run the hardware devices of the laboratory. The experimental findings support the previous research
Hypothesis 2: There will be no significant difference in the cognitive load of students of AR treatment group and Traditional teaching group.

Hwang, Yang and Wang's, (2013) cognitive load questionnaire has been adapted to assess the cognitive load of the two treatment groups. To evaluate the statistical distinction between the two groups, the mean cognitive load scores of the treatment group and control group were compared. The inferential statistics show that the mean results of the two groups differ significantly. The mean value of the treatment group cognitive load was 1.64 and for the control group was 2.03, which indicates that less cognitive load was experienced by the treatment group students compared to the control group students. During the feedback obtained from the students, the students of the treatment group expressed that they were not concerned about the destruction of hardware while working with the equipment as they had already practiced the equipment in the AR learning system. The learners also indicated that they envisioned the front panel of laboratory hardware in the AR environment while using AR learning system, which decreases effort while working on actual laboratory hardware. The outcomes of this study was also validated by the previous studies done by (Cheng & Tsai, 2013; Chu & Lin, 2013; Hadie & Yusoff, 2016; Papanastasiou, Drigas, Skianis, Lytras, & Papanastasiou, 2018), who also found that AR intervention can reduce the cognitive load in different learning scenarios and practices.

Hypothesis 3: There will be no significant difference in the learning motivation of students of AR treatment group and Traditional teaching group.

The learning motivation questionnaire formulated by (Hwang et al., 2013) has been adapted to evaluate the learning motivation of two treatment groups. To evaluate the statistical distinction between the learning motivation of two groups, the mean scores of the treatment group and control group were compared. The inferential statistics show that the mean scores of the two groups do not differ significantly. The mean value of the treatment group's learning motivation was 4.46 and 4.31 for the control group indicating that both group participants were similarly
motivated to know about laboratory equipment. Also, the mean values of both the groups were on the higher side which suggests the high level of motivation for learning about laboratory equipment.

**Hypothesis 4: There will be no significant difference in the technical skills of students of AR treatment group when the design framework of AR Learning System will change.**

In Phase 2 of the experiment, the modifications were done in AR learning system and version 2 of AR learning system was developed. The laboratory skill test has now been used to determine the significant difference in the treatment group laboratory aptitudes. Two parameters were measured in the laboratory skill exam: test scores and time to finish the test. The inferential statistics show that there is a substantial distinction between the pre and post-test scores and the time to finish the test. The mean score of pre-test on function generator was 9.033 compared to the mean score of post-test of 11.400 which suggests that there is gain in the laboratory skills of the students. While the average time to finish the pre-test on function generator was 00:10:26 compared to the average time to finish the post-test was 00:04:31, suggesting that students took less time to accomplish the post-test compared to pre-test on the function generator.

The mean value of the oscilloscope pre-test score was 2.166 compared to the mean post-test score of 11.066 which suggests that there is gain in the laboratory skills of the students. Whereas the average time to complete the oscilloscope pre-test was 00:13:59 compared to the average time to complete the post-test was 00:09:30 suggesting that learners took less time to finish the post-test compared to the pre-test of oscilloscope.

It can be seen from the pre-test scores on the function generator and oscilloscope that it was difficult for students to operate the oscilloscope as the test score was very low. But with the AR intervention, post-test results of oscilloscope have improved significantly so, it can be concluded that the design changes in features of AR learning system have a significantly improved the laboratory skills of the students. Also, learners have taken less time to complete the post-test. This indicates
that with AR intervention, laboratory skills have also improved in terms of time to complete the test.

**Hypothesis 5: There will be no significant difference in the cognitive load of students of AR treatment group when the design framework of AR Learning System will change.**

In Phase 2 of the experiment, the mean value of cognitive load of phase 1 of treatment group is compared to the mean value of cognitive load of phase 2 to analyze the difference between the two stages. The inferential statistics reveal that for the two phases of the research there is no significant distinction between the mean cognitive load score. The mean value of the treatment group’s cognitive load in Phase 1 was 1.64 and the treatment group’s cognitive load in Phase 2 was 1.46 which suggests that the students have observed similar cognitive load during the two phases of the study. The possible reason for this could be that students have already experienced the AR learning system and laboratory equipment during phase 1 of the experiment. Due to which they find it easy to use the AR learning system and laboratory equipment during phase 2 of the experiment.
Chapter 6

Conclusion and Future Scope

The usage of AR technology in engineering education is not very prominent, especially in laboratory courses. This research seeks to comprehend and investigate the potential of AR technology in engineering laboratories.

Therefore, this exploratory study focuses, (a) To evaluate the effect of AR on student laboratory abilities in comparison with traditional instructional methodology; (b) To evaluate the effect of AR learning practices on student’s cognitive load relative to traditional teaching techniques such as printed text with 2D images; (c) To evaluate the effect of AR approach on student’s learning motivation. This chapter presents the conclusion and future scope of this study.

6.1 Conclusion

In this research study, AR technology was utilized to develop learning environment for engineering laboratories. The AR learning system was intended to teach students about laboratory equipment and help them in operating the equipment. The AR learning framework was designed for the table-top environment using Unity 3D game engine and EasyAR SDK was used for AR tracking. Using Autodesk Maya software, the oscilloscope and function generator 3D models have been successfully developed.

The instructional design of AR learning system was supported by technological design of AR which was defined by the principles of cognitive load theory. According to this theory, the extraneous cognitive load relies on the design and presentation of the educational material to the learner. (Sweller, 1994; Sweller et al., 1998). The AR content was designed in such a way that the instructional material was presented to the learners in more effective way. AR has the potential to represent the information through 3D objects along with animation also which
provides better visualization to the students. In this way, AR framework tends to
decrease the student’s cognitive load during the learning procedure.

The primary goal of this research work was to assess the effect of AR
interference on student laboratory aptitudes and cognitive load. The experimental
findings indicate that AR interference has considerable beneficial outcomes on the
student’s laboratory aptitudes. The laboratory skills of the treatment group students
were considerably improved in comparison with the participants of the control
group. These results were supported by the previous study done by (Hwang &
Chang, 2011; Hwang et al., 2016; Ibanez, Di-Serio, Villaran-Molina, & Delgado-
Kloos, 2016; Jou & Wang, 2013; Tran, Radcliffe, & Wang, 2019; Y. Wang, Ong,
& Nee, 2018; Westerfield, Mitrovic, & Billinghurst, 2015) in the different
educational settings. Also, AR intervention has a significant beneficial effect on
student cognition. The experimental findings suggest that less cognitive load was
observed by learners in the treatment group compared to learners in the control
group. The students mentioned in the feedback that they were comfortable
operating the equipment because they already practiced the equipment in the AR
environment. Students have prior experience of operating the hardware devices in
AR, which decreases their mental effort while using the actual equipment. In
previous studies, researchers proposed virtual laboratories and remote laboratories
are not optimal for learners because they take away the student’s practical hardware
experience (Olympiou & Zacharia, 2012; Potkonjak et al., 2016). The blended
learning approach of combining real hardware along with virtual learning
experience is the best way to achieve the learning objectives. In this exploratory
research, AR learning system was used along with real laboratory hardware to
provide learners with the novel learning experience. The AR learning system was
used as teaching aid on which students were given prior training about the
laboratory hardware and after that they were exposed to the real laboratory
equipment.

The findings of the research suggest AR as an appropriate technology for
engineering education, universities and educational institutions should assist
educators in creating distinctive AR environments for learners to improve the
quality of education.
6.2 Limitations of the Study

The research study has a few constraints, one of this study's constraints was the absence of instructors' masking during the interaction and assessment as educators were informed of the two distinct treatments. This was because the laboratory skill exam was a practical examination that cannot be carried out without educators.

The study's other limitation was the small sample size of participants. In this study, only 60 participants have participated in the research study. The research design of this study allows learners to involve in the learning experience for around 90 minutes and requires multiple AR set-up to provide user the AR experience. Also, students have to perform certain task on laboratory equipments on the same time. Due to this it was difficult to handle large sample size for providing AR experience to the students.

6.3 Future Scope

The outcomes of the research suggest AR as an appropriate technology for engineering laboratories and recommend the following suggestions for future research:

- The AR learning framework described in this research has been created for the table-top setting which requires a special set-up for using in laboratories or classrooms. So, in future the learning environment could be developed which can be easily used by the students and teachers in laboratories or classrooms. Also, a comparative research between AR and VR technology with regard to user interface and user-friendliness of the system.
- The present work can be extended to develop an online virtual laboratory in future.
- Also, the AR and VR technology can be utilized with the different pedagogical approaches like flipped learning, collaborative learning and inquiry-based learning to enhance the student experience and expertise.
References


Barak, M., & Asakle, S. (2018). AugmentedWorld: Facilitating the creation of


Bonislawski, M., & Hołub, M. (2018). Teaching modern power electronics-


Chang, S.-C., & Hwang, G.-J. (2018). Impacts of an augmented reality-based flipped learning guiding approach on students’ scientific project performance


Annexure A: Rubrics for measuring Laboratory Skills in Phase 1

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Ratings</th>
<th>Max. Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criteria 1</strong>&lt;br&gt;Connecting oscilloscope and function generator with BNC Cable</td>
<td>1 point&lt;br&gt;Successfully connected oscilloscope and function generator with BNC cable</td>
<td>0 point&lt;br&gt;Not able to make the connection</td>
</tr>
<tr>
<td><strong>Criteria 2</strong>&lt;br&gt;Generate periodic signals (sine, square and triangular wave) of specific amplitude and frequency from function generator</td>
<td>3 points&lt;br&gt;1. Successfully generated the signal from function generator&lt;br&gt;2. Able to set specific frequency of signal&lt;br&gt;3. Able to set specific amplitude of signal</td>
<td>2 points&lt;br&gt;1. Successfully generated the signal from function generator.&lt;br&gt;2. Able to set specific frequency of signal&lt;br&gt;OR&lt;br&gt;Able to set specific amplitude of signal</td>
</tr>
<tr>
<td><strong>Criteria 3</strong>&lt;br&gt;Adjust the controls of oscilloscope to properly display the waveforms</td>
<td>2 points&lt;br&gt;1. Able to adjust the amplitude of signal&lt;br&gt;2. Able to adjust the frequency of signal</td>
<td>1 point&lt;br&gt;Able to adjust the amplitude of signal&lt;br&gt;OR&lt;br&gt;Able to adjust the frequency of signal</td>
</tr>
<tr>
<td><strong>Criteria 4</strong>&lt;br&gt;Measure the amplitude and frequency of signal on oscilloscope</td>
<td>4 points&lt;br&gt;1. Able to calculate the amplitude of signal.&lt;br&gt;2. Able to calculate the frequency of signal.</td>
<td>2 point&lt;br&gt;Able to calculate the amplitude of signal&lt;br&gt;OR&lt;br&gt;Able to calculate the frequency of signal</td>
</tr>
<tr>
<td><strong>Total Points</strong></td>
<td><strong>10</strong></td>
<td></td>
</tr>
</tbody>
</table>
## Annexure B: Rubrics for measuring Laboratory Skills in Phase 2

### On Function Generator

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Marks</th>
<th>Time taken to complete the task (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generate a sine wave from function generator with an amplitude of 5V and frequency of 90 KHz</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Generate a sine wave from function generator with an amplitude of 15V and frequency of 450 Hz</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Generate a square wave from function generator with an amplitude of 2V and frequency of 45 KHz</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Generate a square wave from function generator with an amplitude of 5V and frequency of 750 Hz</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Generate a triangular wave from function generator with an amplitude of 25V and frequency of 550 KHz</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Generate a triangular wave from function generator with an amplitude of 18V and frequency of 85 Hz</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Maximum Marks** 12

### On Oscilloscope

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Marks</th>
<th>Time taken to complete the task (in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure the amplitude and frequency of a given sine wave on oscilloscope</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Measure the amplitude and frequency of a given sine wave on oscilloscope</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Measure the amplitude and frequency of a given square wave on oscilloscope</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Measure the amplitude and frequency of a given square wave on oscilloscope</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Measure the amplitude and frequency of a given triangular wave on oscilloscope</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Measure the amplitude and frequency of a given triangular wave on oscilloscope</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

**Maximum Marks** 12
## Annexure C: Questionnaire for measuring Cognitive Load

<table>
<thead>
<tr>
<th>Mental Load</th>
<th>Strongly Agree (5)</th>
<th>Agree (4)</th>
<th>Undecided (3)</th>
<th>Disagree (2)</th>
<th>Strongly Disagree (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The learning content in this learning activity was difficult for me.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I had to put a lot of effort into answering the questions in this learning activity.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>It was troublesome for me to answer the questions in this learning activity.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I felt frustrated answering the questions in this learning activity.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I did not have enough time to answer the questions in this learning activity.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

## Mental Effort

<table>
<thead>
<tr>
<th>Mental Effort</th>
<th>Strongly Agree (5)</th>
<th>Agree (4)</th>
<th>Undecided (3)</th>
<th>Disagree (2)</th>
<th>Strongly Disagree (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During the learning activity, the way of instruction or learning content presentation caused me a lot of mental effort.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I need to put lots of effort into completing the learning tasks or achieving the learning objectives in this learning activity.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>The instructional way in the learning activity was difficult to follow and understand.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
Annexure D: Questionnaire for measuring Learning Motivation

<table>
<thead>
<tr>
<th></th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>I think learning about laboratory equipments (Oscilloscope and function generator) is interesting and valuable.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>I would like to learn more and observe more in the electronics engineering laboratory course.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>It is worth learning those things about laboratory equipments (Oscilloscope and function generator).</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>It is important for me to learn the electronics engineering laboratory course well.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>I will actively search for more information and learn about electronics laboratory equipments.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td></td>
<td>It is important for everyone to take electronics engineering laboratory course.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>