CHAPTER 1
INTRODUCTION

“The use of technology can play an important role in enhancing the critical role of a skilful teacher, yet the crucial component still remains to be the teacher”

-Anonymous

For Education Technology, there has been an ongoing research to develop and define the actions for the teachers, so that motivation and learning of the students improve in a classroom. During past few years, there has been a constant enhancement in instructional practices. Besides chalkboard teaching, considerable efforts have been taken to enhance the student’s learning, by imbibing technology in education with the help of computers and other multimedia material, simulations, games, smart phones and immersive technology such as mixed reality (virtual or augmented) that can provide complete or partial immersion to its users (Santos et al., 2014). Augmented Reality (AR) has many capabilities; it can provide the users a better learning experience as well as can be helpful for the in-depth exploration of real world information (Johnson et al., 2010). Such learning experience is very significant for education; especially for engineering where “learning by doing” is of paramount importance so that the theoretical concepts are supplemented with the practical experience and the attainment of learning outcome is maximized. When it comes to the discipline of Electronics Engineering, where conceptual models and analogies are equally important along with the presence of physical 3D objects; mental visualization and thus, spatial thinking by the students is highly desired. This is because problem solving in electronics is closely related to physics concepts, which involve the visualization of complex spatial processes and manipulation of the graphs, diagrams and concepts (Smith, 2009). Similarly for programming subjects, visualization and mental management of CPU memory is required for complex programming fundamentals. Spatial ability is one’s ability to mentally visualize, interpret and understand the concepts and processes and is a crucial component for one’s learning. It is highly desirable for courses in engineering and architecture (Gutierrez et al., 2011) and is important for accomplishments in various STEM
domains comprising of Science, Technology, Engineering and Mathematics; and should be incorporated in terms of assessment for educational counselling and selection (Kell and Lubinski, 2013; Ibanez and Kloos, 2018). This ability, although impossible to be taught, can be developed or improved using special training methods such as multimedia exercises, 3D graphics and techniques used for partial or full immersion of users in synthetic environment (augmented and virtual reality). According to Kozhevnikov and Thornton (2006), difference in spatial abilities reflects difference in one’s capacity of visual-spatial working memory; affecting their performance for the tasks involving processing of visual/spatial component. A significant inter-relation between student’s spatial ability and his/her learning and thus, performance in the technical courses has been shown in the literature; thereby, forming the basis of utilizing AR in Engineering Education.

Augmented Reality, as the name suggests, is a technology that modifies the human perception to such an extent that ordinary everyday objects can be seen, heard and felt in a new and enriched way. Human perception of real world to obtain information from their senses is very limited. This limitation can be overcome in certain circumstances, if the original information can be augmented or enhanced. Section 1.1 provides a brief introduction to AR and Section 1.2 details about Spatial Ability and its need for an engineering student for improved concept comprehension. Section 1.3 justifies purpose of the research in AR, spatial ability and engineering education and the complete organization of thesis has been provided in section 1.4.

1.1 Augmented Reality

Augmented Reality (AR) is an immersive technique which is amalgam of the physical (real) and computer generated (virtual) worlds that can enhance the physical information for the users by overlaying the graphical and other kind of virtual content such as text, images and link for online search on the real world objects. In this technology, the physical world is provided with supplementary information in the form of augmentations through the use of graphics or virtual data. A typical AR system makes use of computer graphics and vision based techniques for super-imposition of virtual data on the real scene, thereby providing real and virtual objects seen together for the users.
AR is capable of preserving the sense of realm for the user (of being in real physical world), as the virtual object simulates the physical world objects by providing relevant additional information; and there is not complete but partial immersion of the user in synthetic world. AR has three characteristics which give it a proper definition (Azuma, 1997): first is to provide a combined view of real and virtual objects for the user simultaneously; second, being interactive for the users in real and augmented worlds and third, the capability of being registered in 3D (3-dimensional space) through right placement of real and virtual objects with respect to each other. The relevance of AR with other environments can be shown in the form of Reality-Virtuality Continuum (RVC) proposed by Milgram and Kishino (1994) and is presented in Figure 1.1. The two extremes of RVC are physical and virtual worlds (real world possessing all real objects and virtual world possessing all virtual objects) with mixed reality (MR) in the center consisting of augmented worlds. The real environment is enriched by the presence of virtual objects in Augmented Reality whereas for Augmented Virtuality, the real objects are used for augmentation of the virtual environment.

![Figure 1.1: Reality-Virtuality Continuum (Milgram and Kishino, 1994).](image)

Figure 1.2 explains the flow of steps undertaken for the augmentation to take place. It consists of the following procedure:

1. A view is captured using a camera from a device (smartphone or head mounted display).
2. The captured scene is scanned using some pre-defined algorithms, to find the exact positions for overlaying of the virtual content.
3. After identifying the locations, the system processor sends request to the pre-defined databases for providing relevant virtual content.
4. Finally, the real and virtual information are combined in a single view which is generated by the AR System.

There are three basic strategies which can be used for augmenting the reality (Mackay, 1998): user augmentation, real object augmentation and augmentation of the environment which surrounds the user or real object.

1.1.1 Augmentation of the user

The user carries a device for obtaining the information from the real objects. This approach is useful for medical and defense applications, with the use of AR enabled devices (e.g. Google Glass and Virtual Reality Headsets) to augment the reality for users (Sutherland et al., 2013; Herron, 2016).

1.1.2 Augmentation of the physical object

The real objects can be made to enhance the information for the users by attaching / embedding certain computational device capable of input-output. This approach finds applications in educational settings and professional environments. Electronic paper such as tinker sheets can also be used for modifying the reality for these kinds of scenarios. For ubiquitous computing, Global Positioning System (GPS) can be used (Guan et al., 2011).
1.1.3 Augmentation of the environment near user/object

The surroundings of user and real objects can be enriched with virtual content without modifying the physical world characteristics. The examples of this approach include: generation of 3D (3-dimensional) from 2D (2-dimensional) environment, conversion of images into videos etc.

For development of an AR system, the real environment is sensed and identified using different types of tracking techniques (sensor / vision / hybrid), augmented information is conveyed through different display options (mirror metaphor / glass metaphor) and communication between the real and virtual objects is done through interaction techniques (tangible / collaborative / hybrid). The whole system assembled as a framework (Zhou et al., 2008; Krevelen and Poelman, 2010) is shown in Figure 1.3. Proper alignment of real physical objects with the virtual data is a requisite of an AR system, or the illusion of co-existence of the two worlds would be compromised.

![Figure 1.3: The AR System Framework (Krevelen and Poelman, 2010).](image)

AR is a peculiar example of Intelligence Amplification (Fred Brooks, 1996), as it can make the computer and smart-phones the tools for making a task easier for the users to perform. AR possesses unique affordances like real world annotations, context and vision-haptic visualizations for educational settings, which can affect the learning experience to a significant level (Santos et al., 2014). In education, AR provides learning experience to the users, which eventually helps them to understand the concepts better, gives more accurate perception through the spatial knowledge acquired from interaction and manipulation through AR and thus, has the
potential to overcome the gap between the real and the virtual; and to bring more effectiveness and more attractiveness for real life scenarios for teaching-learning process in educational settings. Wu et al. (2017) emphasized on the fact that AR can intensify the environmental context visualization by augmenting the real world experience of students with dynamic digital materials overlapped with their real environment. Wei et al. (2015) illustrated that AR helps promote the student’s learning motivation and knowledge comprehension through its rich, immersive and interactive context.

1.2 Spatial Ability and Concept Comprehension

Spatial Ability is one’s inherent capability to imagine and visualize the real time phenomenon for grasping and understanding of the information thus perceived. This ability has a significant effect on the intelligence of humans as it processes their working memory; comprising of specific processors for visual and verbal information (Kozhevnikov and Thornton, 2006). This working memory can be tested and developed through development or improvement of user’s spatial skills (the ability for development, design, and manipulation of the real world objects in their mind). This skill is highly needed for engineers and architects for better perception and visualization of concepts and designs. Figure 1.4 shows that spatial skills pertaining to spatial relations (includes mental rotation and perception) and spatial visualization (responsible for mental management of complex shapes and concepts).

Figure 1.4: Sub-components of Spatial Ability/Skills.
Kolb’s (1984) gave an experiential theory, which emphasizes on transformation of experience for knowledge creation contributing for the learning process. This theory states that people learn by creating meaning of what they have understood from their personal experiences. Figure 1.5 represents the Lewinian model for experiential learning process; which consists of four phases: Concrete Experience (for Doing), Observation and Reflection (for Observing), Formation of abstract Concepts and generalization (for Thinking) and Test Implications of concepts (for Planning or Testing in new situations). This is called Kolb’s learning wheel and can be started from any of the four phases.

![Figure 1.5: Lewinian experiential learning model (Kolb, 1984).](image)

Research shows that student’s spatial ability has a significant impact on their learning in the technical courses (Smith, 2009). The students with different spatial ability have been shown to have difference of understanding for the engineering concepts; particularly those, that require the visualization of abstract concepts and the interpretation of graphs. If the students are provided with such tools that they are enabled to visualize what is taught in the classroom, the problem of different visualizations can be resolved. Enhancing perception and visualization can be done by adoption of AR in teaching; as it is capable of providing learning experience to the users, which eventually helps them to understand the concepts better. The spatial knowledge acquired from interaction and manipulation through Augmented Reality may result in more accurate perception thereby making the learning experience more meaningful with involvement of more senses. Since last few decades, the advancements in Computer and Information Systems have made this technology to be used via AR enabled devices (setting up a tabletop environment or allowing
students to use their Tablets / Smart-phones) which makes it cost efficient and thus available for a wider audience as a medium for smarter education.

1.3 PURPOSE OF THE RESEARCH

For technology educators, improvement in teaching through dynamic means of delivery has always been a central consideration. It is assumed that the student’s attention and learning increases if effective means of instructional practices are incorporated in a classroom. The engineering students learn the social and technical skills in form of leadership, critical thinking, and decision-making; with competency in the digital age. Today, most students don’t know how to apply their knowledge in practical scenarios even after acquiring fundamental knowledge of engineering sciences. Previous studies (Contero et al., 2005; Kozhevnikov and Thornton, 2006; Gutierrez et al., 2011) have shown that students’ spatial and cognitive skills contribute towards their understanding of science, technology, and education. Spatial visualization skills are one’s ability to mentally imagine the analogies and abstract concepts, thereby making the learners understand the fundamentals with minimum cognitive load. Due to different spatial visualization, it is not possible for all the learners to apply concepts in similar practical ways. Therefore, it is important to look for the methods which are capable of improving the concept comprehension of learners by bringing everyone to nearly equal level of learning, even if they possess different abilities for spatial visualization. Literature also indicates that better learning takes place in students when their instructor uses 3D representations for better visualization of engineering concepts and theories. The field of electronics engineering is considered to have higher levels of abstraction (Smith, 2009), and requires high spatial visualization among students. Out of many instructional practices, AR has benefitted almost every area in education including primary school (Efstathiou et al., 2018), K-12 education (Santos et al., 2014; Wu et al., 2017), engineering (Chen et al., 2017), geography (Turan et al., 2018) or medical education (Sutherland et al., 2013; Herron, 2016). AR works with computer-generated virtual content which can be amalgamated into physical environment containing real objects (Azuma, 1997), and helps to improvise users’ spatial and cognitive abilities (Gutierrez et al., 2013; Slijepcevic, 2013). Researchers have used AR for various laboratory courses in electronics/electrical engineering by
allowing the students for data visualization (Anastassova et al., 2014; Odeh et al., 2013). But, the need for theoretical concepts and their understanding through AR still remains unexplored. Such concepts have never been demonstrated in the form of laboratory experiments or explained through simulations in CG space (computer generated imagery). Also, the AR has been used in the form of fixed predefined methods (Drljevic et al., 2017), rather than being flexible as per user requirements, thereby, not being of any help to the students possessing different visualization abilities. Thus, the present research investigates and answers the following research questions:

a. Does there exist a framework, which uses AR for teaching in engineering education as an instructional tool?

b. How effectively AR performs as a learning tool, when compared with other instructional treatments, for the working memory and consequently on the learning achieved by a student?

c. Can AR be used for improvement of the concept comprehension by learners with different spatial abilities?

This work presents an adaptive AR-based approach (Ghouaiel et al., 2014) in the form of an interactive learning environment available in two different variants. One of the variants makes use of device camera from a tablet or Smart-phone and displays augmented content through vision based target tracking suitable for Mobile AR. The other variant is equipped with a fixed camera with desktop and utilizes vision based tracking for real-time objects, providing user interaction in real environment as well as in the augmented space simultaneously. This method is termed as Table-top AR. The topics from control theory have been selected for system implementation because of two reasons. First, students find the topic as interesting and difficult to understand at the same time using traditional instructions in the classroom. Second, the literature indicates that except one study (Andujar et al., 2011), AR has never been considered for this topic. The present system was evaluated by presenting it to undergraduate students from engineering courses for learning and understanding control theory fundamentals, and then conducting a questionnaire-based survey as pre-tests at the beginning and post-tests at the end of the semester to find the determinants of AR on their concept comprehension while emphasizing on a user feedback for motivation, usability, and satisfaction for using AR in classroom settings.
The combination of AR technology with educational subjects is capable of bringing enhancement, effectiveness and attractiveness in the process of teaching and learning. This research focuses on the educational applications of AR primarily in two major areas: Student’s working memory limitations and concept visualization in engineering education, and how it pertains to comprehension and motivation for a particular concept. These areas are very crucial components of the research which may be conducted to prove effectiveness of Augmented Reality as an instructional technology in education. As a blend of physical and virtual environment, AR has several unique properties: it has excellence at representing the spatial information and capability of allowing the learners to add a tactile sensation to their learning experience when some interfaces are added. Also, this technology has the potential to promote deep understanding of the concepts to the learners who have different spatial visualization abilities; thereby enhancing their learning by reducing the mental effort more than other styles of teaching. Due to these properties, AR should be examined as a viable instructional technology from an educational and learning perspective.

1.4 ORGANIZATION OF THESIS

To answer the above mentioned research questions, this report is organized into seven chapters, chapter 1 being the introductory chapter for context and motivation. Figure 1.6 details the structure of the present research and related published articles.

Chapter 2 provides a background for using AR in education, training, and improvement of spatial skills of engineering students through an extensive literature review. This chapter outlines the relevant research on use of interactive learning systems (mobile and table-tops) in education, especially used for higher/engineering education scenarios.

Chapter 3 conceptualizes the framework for present research. This consists of the foundations for design of an interactive environment based on the technology of Augmented Reality. It provides the glimpse into two exploratory cases studied for design improvement and implementation in classroom teaching. Case 1 is a pilot study that was carried out on a small
group of students to find the design feedback through student validation. This feedback was utilized to make improvements in user-interface and other aspects of the ARLE and implemented as Case 2 on another group of students. The second case describes an empirical study to evaluate the determinants of using ARLE on student’s concept comprehension in the classroom settings. Various schemes used for analysis and validation of the proposed design are also discussed in this chapter.

Chapter 4 explains the design and implementation of an adaptive ARLE in the form of two variants: Mobile and Table-top. Various design implications are discussed in this chapter concluded by the challenges faced during design and implementation of the ARLE.

Chapter 5 discusses evaluation and analysis of research methodology followed while deploying the ARLE in classroom settings. The experimental set-up used for both the case studies have been discussed in detail with the pictures of experimental class conducted to evaluate the present design.

Chapter 6 presents the results and discussion on implementation of ARLE for teaching-learning of chosen concepts in a classroom scenario, and effect of different instructional treatments on the learning of students. The investigation is done in the form of descriptive and inferential statistics. This chapter analyzes the primary data collected in the form of feedback questionnaire for design of ARLE, the results of paper folding test (PFT) and purdue spatial visualization test: rotation (PSVT:R) to determine the spatial ability of research participants, technical test outcome based on the questionnaire from the chosen topic for ARLE implementation and student’s response for the feedback questionnaire to test the motivation of the learners participating in the study. Testing of hypothesis is done in this chapter to support the present work by answering the research questions. This analysis validates the use of ARLE in classroom settings, and purpose of the present research.

Chapter 7 revisits the contributions of present work ensuring that each objective stated in the research has been addressed and all research questions have been answered. Here, the thesis is
concluded for the present work, with discussion on the limitations of the approach, providing a basis for the future research.

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Figure 1.6: Structure of the Research and related published articles.