Enriching Student Learning Experience using Augmented Reality and Smart Learning Objects

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ABSTRACT
Physical laboratories in Electronic Engineering curriculum play a crucial role in enabling students to gain "hands-on" learning experience to get a feel for problem-solving. However, students often feel frustrated in these laboratories due to procedural difficulties and disconnects that exist between theory and practice. This impedes their learning and causes them to lose interest in the practical experiment. This research considers the approach of ubiquitous computing to address this issue by embedding computational capabilities into commonly used physical objects in electronics lab (e.g. breadboard) and making use of mobile Augmented Reality application to assist students. Two working prototypes have been proposed as a proof-of-concept. These are (i) an AR based lab manual and circuit building application, and, (ii) Intelligent Breadboard - which is capable of sensing errors made by students. It is posited that such systems can help reduce cognitive load and bridge gaps between theory and practical applications that students face in laboratories.

CCS Concepts
• Human-centered Computing →Human computer interaction (HCI) → HCI design and evaluation methods → Usability testing. • Human-centered computing → Ubiquitous and mobile computing.

Keywords
Augmented Reality; Smart Learning Objects; Embedded Intelligence; Education.

1. INTRODUCTION
Studies [6] show that students involved in performing experiments in laboratories often get frustrated due to faulty equipment, troubleshooting problems and are unable to understand the procedures as prescribed in a lab manual or by a lab instructor. This impedes their learning flow. In most cases, experiments are performed on a trial-and-error basis by students who reduce their 'learning' component – the very purpose of the experiment being part of a prescribed curriculum. Further, given the limited amount of time in which these experiments need to be performed within a fixed timetable slot, students' motivation is mostly hinged on getting over with the ritual rather than learning.

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Owing to a highly situated nature of learning in laboratories, it is important to design instructions innovatively to help learners relate to the practical applications of the concepts and principles covered in labs.

This research considers the approach of ubiquitous computing to address this issue – in Electronics Engineering by embedding computational capabilities into commonly used physical objects in Electronics Lab (e.g. breadboard) – also referred to as Smart Learning Object (SLO), and making use of mobile Augmented Reality (AR) application to assist students in practical laboratories. The primary outcome of this research is to formulate development of heuristics for developing embedding intelligence into objects and AR applications to indicate a way to conceptualize tomorrow's instructional learning mediums.

Two prototypes have been developed for the purpose of subjecting them to user testing as a part of this experimental investigation. The primary objective of these experiments is to compare students' cognitive load while learning electronics practical using our developed prototypes.

The following research questions are being investigated:

- *Q1: Are there guidelines /heuristics for Embedding Intelligence in objects in electronics lab? If not, can they be developed based on experiments?*
- *Q2: How much intelligence and what type of intelligence needs to be embedded into objects? In what form should it be embedded?*
- *Q3: How to establish interaction between such objects and the user? Which usability principles apply?*

2. BACKGROUND AND RELATED WORK
Estrada et. al, (2012) [1] reported that almost 78% of the students feel frustrated while conducting experiments in the lab due to lack of understanding of equipment and unclear instructions. This frustration further leads to boredom, which is even worse as students stop making an effort to learn at that point [2]. Studies, as reported in the literature [3] on students' learning in laboratories highlight that it is a place of information overload. These studies also suggest that although students gain hand skills and techniques, they lack connections with underlying theory. In the context of Electronic Engineering lab, Watai et al., 2005 [4] states that – "students often get bogged down with procedural and practical difficulties that distract them from the concepts and objectives of the labs and prevent deeper inquiry." Investigations in cognitive science [5, 6] suggest that for deeper learning to take place, learners should understand how to use knowledge as a problem-solving tool. Hence it is important to design instructions and instructional environment that helps students situate learning in an approximation of the real world [4] and decrease their cognitive load.

Although Windows, Icon, Menu, and Pointer – Graphical User Interface based simulation software tools are employed to help students understand and visualize the experiment, they inhibit ideation [7] and effect of physicality that students experience while interacting with actual laboratory artifacts. Studies [8, 9] on the importance of laboratories suggest that physicality is necessary for knowledge building and learning.

The use of AR and smart objects can retain the effect of the physicality of using actual hardware and help distribute the cognitive load of students [8, 10]. Studies [11, 12] on ubiquitous learning environments present innovative approaches that integrate wireless sensor networks and context-aware technologies in laboratories to monitor students' learning skills and guide inexperienced researchers in operating equipment in laboratories. Hwang et al., (2009) [12] also defines the tutoring strategy based on IF-THEN rules to guide learners in such a system. Juo et al. (2013) [11] accessed the use of wireless sensor networks for ubiquitous tutoring in laboratories and found that use of such devices facilitated interest, motivation and learning amongst students. Goyal et al., (2013) [13] proposed direct interaction with PCB using a probe to obtain just-in-time information regarding the schematics. Such a system shows potential for adoption as an instructional tool in the electronics lab.

Further, a study [10] on AR based learning experience emphasized upon the affordance of AR technology. These include - Real world annotation, Contextual Visualization and Vision-haptic visualization. The authors also suggest that AR learning experiences encourages exploration ability of students, promotes collaborative learning and increases concentration owing to its immersive nature. Studies [14, 15, 16] highlighted the potential of AR for engineering education in terms of greater collaboration between students and instructors, fostering creativity and imagination and authentic learning environment for various learning styles. A demonstration for circuit building through AR has been presented in [17].

The literature survey carried out so far reveals that although substantial research work has been published and conducted in the field of AR and Smart Objects, their applications in the context of improving the hands-on learning experience of students in electronics lab has yet to reach its potential. Innovative approaches that rely on digital technologies are required for reducing the cognitive load of students in electronics laboratory.

3. RESEARCH METHODOLOGY AND HYPOTHESIS

This research utilizes both qualitative and quantitative data collection and is mainly rooted in a User-Centered Design approach as practiced in Human-Computer Interaction (HCI) and Interface Design. Questionnaires, Semi-structured interviews, and Observational Studies are used as the instrument for data collection. The following working hypotheses are being tested:

H1: AR application and SLO embedded with intelligence are expected to reduce the cognitive load of students in electronics lab practical by a range of 10-12%.

H2: AR application and SLO embedded with intelligence are expected to increases students' performance in electronics lab practical by a range of 5-10% than their current level.

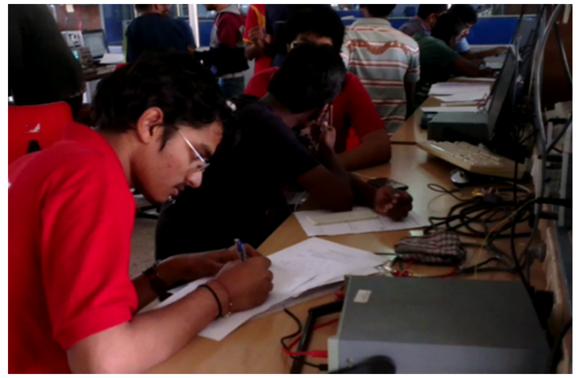

Figure 1. Contextual Inquiry was conducted with undergraduate students in the electronics lab.

3.1 Contextual Inquiry and Need Assessment

A contextual inquiry was conducted to conceptualize prototypes for assisting students in the electronics lab (see Figure 1). Twenty (n=20) second-year undergraduate students from electronic engineering branch were interviewed and presented with storyboards of conceptual scenarios of SLO in laboratories. In addition to this, an open-ended questionnaire was given to twenty-three (n=23) first-year undergraduate students asking them to describe anything they mainly found good or frustrating while performing experiments. The scenarios were presented to understand user perception, acceptability and the need for such technologies. Students were asked to rank the storyboard according to their needs. Based on this user study, two working prototypes have been developed for the purpose of user testing and have been discussed in the section below. These prototypes were designed to be embedded with intelligence that could assist students in a manner similar to that of a human tutor during the practical laboratory session.

Usability testing methods for conceptualizing, modeling and prototyping SLO and AR in a ubiquitous computing scenario were used extensively.

4. PROTOTYPES

4.1 Augmented Reality Based Instructions

An AR mobile application for Android platform has been developed on Unity 3D [18] using Vuforia SDK [19]. A marker which could be easily printed on a paper and clipped onto the breadboard during circuit assembly (see Figure 2c) was used. This marker helps the mobile application overlay virtual digital content like 3D/ 2D images and videos onto the real world scenario (see Figure 2a). The application also utilizes a marker-less feature for AR to provide instructions to students in forms of videos and voice, (see Figure 2b and 2d). Whenever the mobile AR camera is pointed towards a specific figure on student's lab manual, a corresponding video instruction is displayed to the student about that experiment. For example – theoretical working of an RC circuit and the waveforms on charging and discharging of capacitors. Similarly, on pointing the mobile AR camera towards Cathode Ray Oscilloscope (CRO), virtual AR buttons show up on the mobile screen that provides voice-based instructions when pressed for corresponding features on CRO interface. The main functionalities of this AR application are:

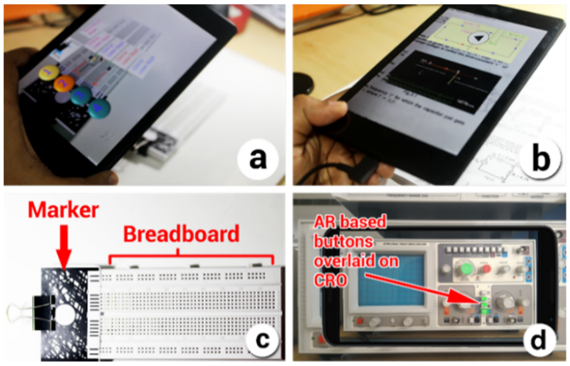

Figure 2. Features of AR instructional application. a) 3D circuit assembling instruction, b) Video instructions, c) AR Marker clipped to breadboard, d) Interface for providing instruction to operate CRO based on marker less AR.

- Marker and Marker-less AR tracking; (ii) Providing step based visual instruction regarding circuit assembly,
- Giving voice based instructions for circuit assembly,
- Provide visual and voice based information regarding electronic components,
- Showing videos regarding theoretical aspects of experiment (for example: working of RC circuit and flow of electrons),
- Providing voice based assistance for operating CRO, and,
- Asking enquiry-based questions for various experimental steps.

4.2 Intelligent Breadboard

Since users often reported they face a problem with debugging of electronic circuits in electronics laboratory, an Intelligent Breadboard (IB) prototype was developed to sense input and nodal voltages of the circuit. This breadboard could communicate with user's smartphones or digital tablet via Bluetooth which acted as a mediator to provide information and voice-based instruction regarding mistakes made to users. The voltage sensors were placed in each row of the breadboard to detect the nodal voltage of the circuits. These nodal voltages corresponded to a very specific experiment for which task flows and errors were stored in the database. By doing so, the IB acted as SLO. This breadboard is limited in its functionalities at this stage; i.e., the intelligence is embedded only for a specific experiment only. The prototype was developed using microcontroller Arduino UNO and 1-Sheeld. Figure 3 represents a block diagram of IB's working. Whenever an error was sensed on

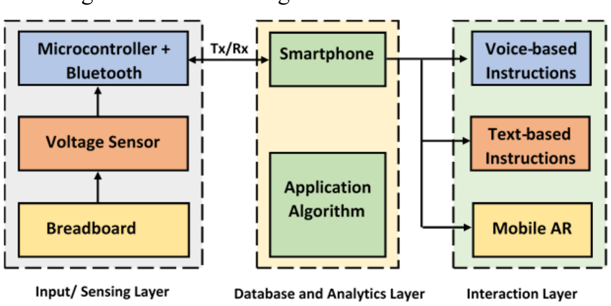

Figure 3. Block diagram showing the working of an Intelligent Breadboard

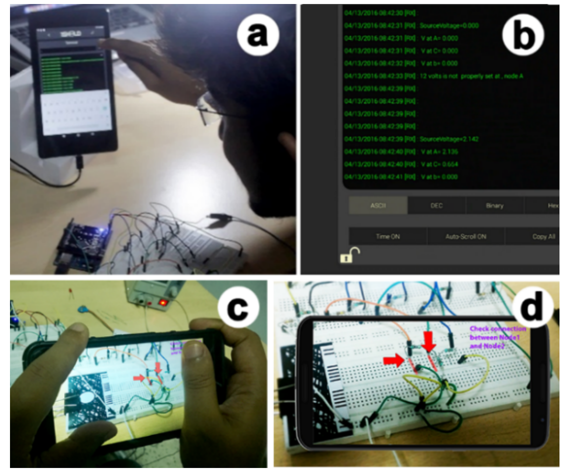

Figure 4. Intelligent Breadboard setup. a) User interacting with IB via digital tablet. b) Screenshot of text based instructions displaying error made by user. c, d) Use case of user being notified on AR interface about their mistakes

the breadboard through voltage sensors, the microcontroller would serially communicate using Bluetooth with the smartphone via which instructions were provided to the user. The types of error that could be deducted included overvoltage, loose connection at particular rows of the breadboard, input voltage, and nodal voltage. Based on the type of error, corresponding instructions were generated for the user. These instructions could be provided to the user through text-based and voice-based functionalities. Figure 4a depicts a user working on an IB prototype setup and interacting with a digital tablet. Figure 4b shows the user interface on tablet. This prototype requires further development.

4.3 Using AR and SLO in Conjunction

In addition to above features, SLO can also be used in conjunction with AR to provide simultaneous visualization and notification to users. Figure 4c and 4d depicts one such use case where the IB sends error information to mobile AR interface serially via Bluetooth. Correspondingly, the AR shows users the mistakes they have made while rigging the circuit. Such type of systems can prove beneficial for students while working on complicated circuits.

5. USER STUDIES

Two user studies in live laboratory session have been conducted with the first prototype, i.e. AR application (refer Figure 5). Observations were made regarding how students used AR application with their experiment. They were also asked to share their experience and feedbacks. These studies informed the design process and gave insight into the development of such learning systems for engineering lab course. These studies have been described as follows:

5.1 Study 1

An initial study was conducted amongst ten students (n=10), randomly selected, to gain feedback regarding the application and analyze users need regarding AR based learning systems. Feedbacks were also taken from course instructors and lab assistants regarding the usefulness of this application in the lab. Based on the feedbacks collected from Study 1, Think Aloud sessions and interviews were conducted for the further development of AR application and SLO based learning systems.

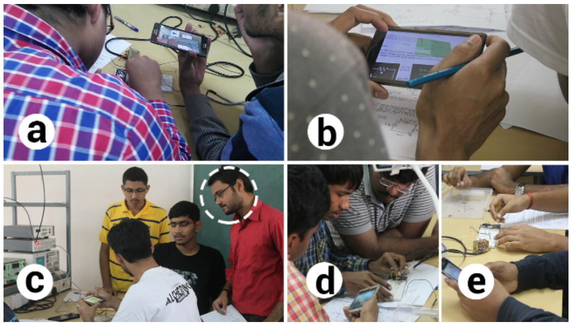

Figure 5. Use of AR application in live laboratory sessions. a,b,d,e) Students using AR while conducting experiments. c) AR invokes further interaction between students and lab instructors, in white circle, regarding theoretical aspects of the experiment.

5.2 Study 2

This study was carried out amongst thirty-six students (n=36). It was observed that the AR application increased the interaction between lab instructors and students and invoked discussions regarding theoretical aspects of the experiments (see Figure 5c). The students often used video feature to verify their output and understand the working of circuits. They also used AR based circuit assembly instructions while rigging the circuits on a breadboard. Course instructors also commented that such application could help students deviate from rote learning and help connect theory with practice in labs. The students and instructors perceived the application to be highly useful and were willing to adopt it for future use.

6. RESEARCH PLAN

The progress so far has been validated in part with encouraging positive results. More user studies are planned to be conducted. At present, further development is being done on the developed prototypes to make them suitable for the purpose of field study for large scale user-testing. The study will explore the potential of these prototypes in terms of reducing the cognitive load of students in an electronics lab and try to understand and specify the extent of human interaction with SLO and AR systems in educational settings by leveraging the intelligence of such systems. The user studies will be conducted with second-year electronic engineering undergraduate students in the basic electronics lab. Both qualitative and quantitative methods of data collection will be employed. Usability testing methods will also be utilized for conceptualizing and accessing the usefulness of the prototypes.

The findings of these user studies, which are planned to be conducted as a part of this experimental investigation, would be useful in developing heuristics for embedding intelligence into already existing laboratory equipment and AR applications for engineering curriculums.

7. SIGNIFICANCE AND CONTRIBUTION OF THIS RESEARCH

This research exploits and explores the use of AR and SLO as an instructional medium for students in crowded electronics laboratories with fewer resources at engineering institutes. The study also demonstrates a potential way to implement emerging technologies of AR and SLO in authentic classroom settings and proposes the heuristics for designing learning systems with embedded intelligence.

The main contribution of this work is in offering novel tools for situated learning in an engineering higher education context in the form of Augmented Reality application and Smart Learning Object.

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