Automating Engineering Educational Practical Electronics Laboratories for Designing Engaging Learning Experiences

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Abstract. This paper presents a work on understanding the effect of automated systems on learning experiences of students in practical electronics laboratory sessions. Here automation refers to the ability to provide students with contextualized information and instructions to rectify mistakes made while conducting practical experiment. A system employing mobile augmented reality (AR) and a debugging tool to assist students with physical circuit prototyping was developed. The AR provides active visualization to students regarding practical experiment. The debugger tool senses errors made while prototyping of electronic circuits on breadboard. The proposed system, named Smart Learning System, has shown to improve students' engagement in practical laboratory sessions and improve laboratory dynamics by reducing the workload of instructors.

Keywords: Augmented reality · Smart objects · Engineering education Artificial intelligence · Qualitative HCI

1 Introduction

Educational laboratories of engineering institutes play an important role in nurturing hands-on skills in students. However, due to a number of constraints faced by students in these laboratory sessions, in terms of lack of understanding about equipment, equipment issues and debugging problems, etc., learning often becomes frustrating and cumbersome. Such issues also increase the workload on laboratory instructors who need to tend to a large number of students. This paper presents a work on understanding the use of augmented reality (AR) and intelligent automated tool in complex environments of educational laboratories to help create engaging learning experiences and improved classroom dynamics. The specific focus is in context of practical electronics laboratory session of engineering institutes. Students in these practical electronics laboratories are required to assemble physical circuits on a Breadboard [1] – a passive device used for prototyping physical electronic circuits. However, despite its widespread use, it remains prone to a number of issues such as loose wire connections, misplacements of electronic components and faulty connections [2]. In addition to assembling circuits in laboratories, students are required to operate test

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equipment like cathode ray oscilloscope, variable power supplies, function generators and at the same time make connections between theoretical and application aspects of the experiments. All these steps combined together pose various constraints and challenges for students – thus leading towards increased workload, poor learning experience and poor learner's satisfaction. The students also rely constantly on laboratory instructors for assistance. However, teaching a large number of students of varied background is often quite difficult for instructors [3]. Challenges also arise for laboratory instructors regarding teaching, giving time to students and often handling a large number of students – who face difficulties in a time-limited laboratory session.

To minimize such factors, a tool to automate circuit-debugging process for use with augmented reality (AR) is proposed that helps students to learn in engaging ways. The system provides contextualized information to students, helps them relate theory with practice and assists them in tasks like rigging up circuits and operating test equipment. Problems faced by students while circuit assembly on the breadboard are automatically detected and highlighted using the circuit debugger. The main idea is to design an intelligent automated system capable of assisting students and facilitating teaching in practical electronics laboratories. For designing such system, learning and knowledge has been derived from understanding human tutoring in practical laboratory sessions by utilizing a user centered design (UCD) [4] approach.

Since human tutoring, especially in the laboratory sessions, is mainly based on imparting experiential knowledge, it is important to provide it with the ability to guess the problems or difficulties being faced by students and guide or instruct them like human teachers. To model and design this experiential or heuristic reasoning based instructional capabilities in, emphasis was placed on user-centered design methodology and an interdisciplinary approach was adopted to combine the practices of Human-Computer Interaction (HCI) with those of Artificial Intelligence (AI). This method is mainly based on Herbert Simon's philosophy of considering AI as an empirical science [5]. The study also follows the approach of ubiquitous computing [6] as envisioned by Mark Weiser, where every day mundane objects are embedded with computational capabilities, with focus on developing learning aid for future classrooms. The proposed circuit debugger tool is based on this approach and falls under the category of Smart Learning Objects (SLO) – which are physical objects with embedded intelligence and sensors used in educational environments. The proposed Smart Learning System (SLS) utilizes both SLO and AR. AR provides an excellent means to establish interactions between users and everyday objects through interactive visualizations by superimposing computer generated graphics onto real environment.

It is posited that such augmentation and automation technologies, based on SLO and AR, can help leverage learning experiences of students in educational spaces, improve instructors teaching satisfaction and help create better learning environment.

2 Literature Review

Research studies [7, 8] on students' learning experience in engineering laboratories highlight that nearly 78% of the students feel frustrated in laboratories due to issues like troubleshooting of equipment and lack of understanding regarding experiment.

This frustration causes boredom in students which prevent them for further learning. Pass et al., Sweller et al., and Watai et al. [7, 9, 10] also report that laboratories are a place of extreme cognitive load for students which hinders with their learning process. The authors highlight need for innovative methods to provide contextualized instruction to students in laboratories. Further investigations by Booth et al. [11] report the problems faced by users during prototyping of electronic circuits and discuss the need for supportive ways to educate and assist user in these task. Dede [12] posits that the use of smart objects with embedded sensors and intelligence can help distribute cognitive load of student. Using such devices in educational settings gives rise to Ubiquitous Learning Environment (ULE), which can allow sensing learner's situation and provide adaptive support to them [13, 14]. Mattern et al. [15] discussed the capabilities of physical smart objects in terms of embedded information processing, intuitive user interface, context-awareness and highlighted the use of smartphones as a mediator between people and smart objects. Studies [13, 14] present conceptual scenarios on the use of such smart objects in laboratories to sense physiological and psychological parameters and provide intelligent feedback through text-to-speech systems embedded in the objects. Further investigations [16, 17] have been made on type of intelligence to be embedded into laboratory equipment and objects to minimize cognitive load of students in electronics laboratory. Drew et al. [2] presented a novel tool to automate checking of circuits on breadboards. Published research studies [18, 19] illustrate the use and effectiveness of mixed and augmented reality based learning systems. These contributions show that using such systems can provide enhanced learning experience in pervasive computing environment and help distribute workload of students by providing visualization capabilities.

These research works also suggest that although a significant research has been published and carried out in the field of AR and Smart Objects, their applications in context of improving learning experience of students in electronics laboratory is highly limited. Further discussion on developing guidelines for such learning aids are required. Research studies discussed by Gonçalves et al. [20] present an overview on user experiences through the use of smart and pervasive technologies to improve the quality of human-workspace interactions in various contexts including education. These studies broadly fall under human-work interaction design framework [21] that urge a need to explore possibilities of utilizing emerging information and communication technologies to improve user's interaction with workspace and its related nuances. This paper broadly falls under this human-work interaction design framework and presents a basis for design of an automated system utilizing AR and smart object for assisting human learning in practical electronics laboratories.

3 Research Questions and Objectives

This study considers the approach of ubiquitous computing [6] to address the difficulties experienced by students in electronics engineering practical laboratories by embedding computational capabilities into commonly used physical objects in electronics laboratory (e.g., breadboard) and making use of mobile AR. The primary outcome of this research is to understand how automation in practical electronics laboratories can help design engaging learning experiences for students and what influences it has on the laboratory dynamics.

A Smart Learning System prototype was developed for this experimental investigation as a part of automation solution in practical electronics laboratories. The primary objective of these experiments is to access students' learning satisfaction in electronics practical using the developed prototype.

The following research questions were investigated:

Q1: How to create automation in practical electronics laboratories to create engaging learning experiences?
Q2: What effect will automation have on learners' satisfaction?
Q3: Will students find automation useful to be adopted in practical laboratories?

The following hypothesis was formulated and tested:

H1: A positive relationship exists between learners' satisfaction and the reuse intention for SLS.

4 User Research and Methodology

This research utilizes both qualitative and quantitative methods of data collection and is mainly rooted in a UCD approach as practiced in HCI. Observational studies were carried out in live laboratory sessions and semi-structured interviews of teachers and students were conducted. Field notes, audio and video recordings were made for all these sessions. The collated data was analyzed using content analysis technique. Twenty (N = 20) second year undergraduate students from electronic engineering branch were interviewed and presented with storyboards of conceptual scenarios of SLO in laboratories. Laboratory instructors (N = 2) were also involved in the design process to provide continuous insights into laboratory practices and feedbacks on prototype development.

4.1 Scenario Based Design Approach

Scenario based design technique utilizing conceptual storyboards was utilized. The idea of storyboarding approach was adopted from authors Davidoff et al. [22] to explore divergent design concepts. This methodology allowed understanding about the concreteness of the proposed solution and helped evoke further requirements for analysis and technology probe [23]. It also enabled understanding of user's perception, acceptability and need for new technologies. Students were asked to rank the storyboard according to their needs. The storyboards depicted possible interactive learning systems that were envisioned to assist students intelligently in practical electronics laboratory sessions as well as assist instructors in teaching. Out of three conceptual scenarios presented, students ranked scenario 2 highest, see Fig. 1.

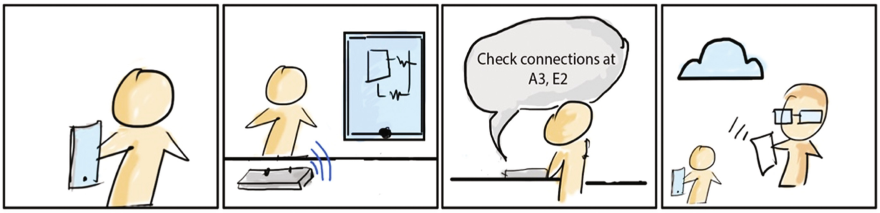

Fig. 1. One of the conceptual storyboard presented to students which depicts the use of SLO and AR in practical lab sessions. The storyboards were used to conceptualize future learning aids with embedded intelligence.

The scenario illustrates a laboratory session where students perform their experiments on a breadboard with circuit debugging capabilities. This breadboard is also referred to as SLO. The breadboard is connected to a computer or digital tablet that shows visualizations for circuit assembly. The system is also able to detect wrong connections and pin-point it to students and guides them by instructing about various theoretical concepts of the experiment. The students can simultaneously update their experimental readings to their records and upon completion of experiment; this record is sent to their instructors for evaluation. The students were strongly able to relate to this depiction but pointed out that such a learning system alone will not be sufficient in laboratories. However, they also suggested a strong need for laboratory instructors to help them out with their experiments instead of completely relying automated systems.

4.2 Interviews

Face to face open-ended interviews were conducted amongst these N = 20 participants. The participants were undergoing or had already undergone and finished basic electronics laboratory course and could narrate their experiences and difficulties faced in laboratories. The ages of these student participants were between 18 to 20 years with an average age of 19 years. Students were asked to describe the difficulties experienced by them in practical laboratory sessions. In addition to students, laboratory instructors (N = 2) were also interviewed to get insights into difficulties experienced by them while teaching in practical laboratory sessions. Table 1 presents a few responses of instructors regarding difficulties experienced while conducting practical laboratory sessions.

Table 2 presents a few excerpts from students' interviews that highlight some of the problems described by them.

The interviews provide an insight into different types of difficulties experienced by students in terms of lack of contextual information, ability to operate various equipment and difficulties experienced in physical circuit prototyping. These difficulties can be categorized under different activities that are required to be performed by students in

Table 1. Qualitative responses of laboratory instructors (N = 2) regarding difficulties experienced in laboratory

Participant	Responses
I1	*"Most of the students think that input devices, output devices and the circuit itself were connected properly even if they are not. General practice is to verify the inputs and check the intermediate results compared to expected results. However, this procedure is difficult especially when the number of stages are more or circuit having more components…"*
I2	*"…more practical knowledge on use of equipment such as CRO, function generator should be given. …even we face difficulties in operating CRO…."*

Table 2. A excerpts from a few students' interviews

Participant	Responses
S1	*"… There are many faulty equipment…breadboard were faulty, we need to ask for new breadboards… In digital electronics, we didn't know many things. We were able to perform only after coming to lab and asking friends… Big circuits take time and show problems… leads to frustration but after it works, we feel excited…"*
S2	*"…sometimes the fault is only realized after implementing the whole circuit and when it leads to wrong output or other problems…can't be pointed out initially…"*
S3	*"…lab manual only tell procedures, not the implications of errors or combination of component arrangement…"*
S4	*"Lab based learning is very helpful than doing on paper and pen. Sometime we design some circuit on paper and think that it will work. But when we practically perform it, the situation is different. That time we realize and learn what are the mistakes we are doing"*

order to complete the experiment. These activities are: Referencing, Assembling, Operating test equipment and Reporting [24]. The difficulties under each of these activities can be broadly categorized as follows:

Referencing: lack of contextual information, gaps in explanations between theory and practical experiment.
Assembling: loose wires and improper connection on breadboard, wrong connections, wrong electronic components used, power supply issues.
Operating test equipment: lacking understanding about equipment functioning, faulty equipment
Reporting: wrong measurements, wrong calculations.

These difficulties hinder with students' learning experience in electronics laboratories as they often have to struggle with trivial issues such as identifying loose wire connections. Various research studies have focused on improving the laboratory objectives and activities to overcome such difficult situations. Studies in HCI [2, 25] have focused on developing tools to overcome these challenges for end users - mostly involved in hobby electronics. Such tools can help automate trivial tasks like identifying loose wires and wrong connections. However, in case of educational laboratories, students require more than just simple prompts regarding mistakes made. The prompt needs to be instructional in nature through which students can derive learning, self-reflect upon their actions and gain the ability to understand where they are going wrong and why they are going wrong. In such cases, the automation requires a certain level of intelligence that is able to assist student in – a manner similar to that of a human tutor.

Based on this understanding derived from user research studies, a SLS was conceptualized, designed and developed so that it could assist students relate theoretical concepts, assemble circuit and debug physical circuits as well as get instructional prompts to help them understand the activity they performed. The SLS was embedded with intelligence that could assist students troubleshoot difficulties faced during physical circuit prototyping on breadboard. The following section describes the SLS prototype.

5 Smart Learning System Prototype

The SLS prototypes consists of an AR based application and an intelligent breadboard. The AR application provides active visualization to students by providing 3D animated instructions regarding circuit assembly on breadboard, operating test equipment in lab, for example a cathode ray oscilloscope (CRO), and, on-spot videos regarding theoretical aspects of the experiment. The application utilized both marker and marker-less tracking to overlay 3D and 2D graphics onto real space.

When smartphone or digital tablet were pointed towards the figures given on laboratory manual or breadboard circuit, on-spot videos and 3D graphics were overlaid onto work environment, as shown in Fig. 2(a, b, c, d).

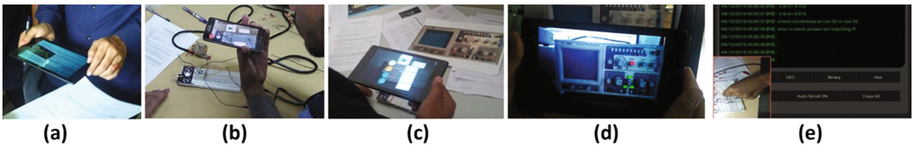

Fig. 2. SLS Setup consisting of AR and circuit debugging tool. (a) Video instructions overlaid on a lab manual, (b) Breadboard attached with marker, (c) Close-up view of the 3D graphics overlaid on breadboard, (d) Operating instructions for CRO, (e) Snapshot of instructions provided by circuit debugger on digital tablet.

Further, to aid usability and help students working on circuit assembly, an assistive instructional AI was embedded in the debugger module attached to the breadboard that sensed input and nodal voltages of the circuit. This module could communicate with user's smartphones or digital tablet via Bluetooth and acted as mediator to provide information and voice-based instruction regarding errors made by users, see Fig. 2(e). The types of error that could be sensed are overvoltage, loose connections on breadboard, input voltage and nodal voltage. Based on the type of errors sensed,

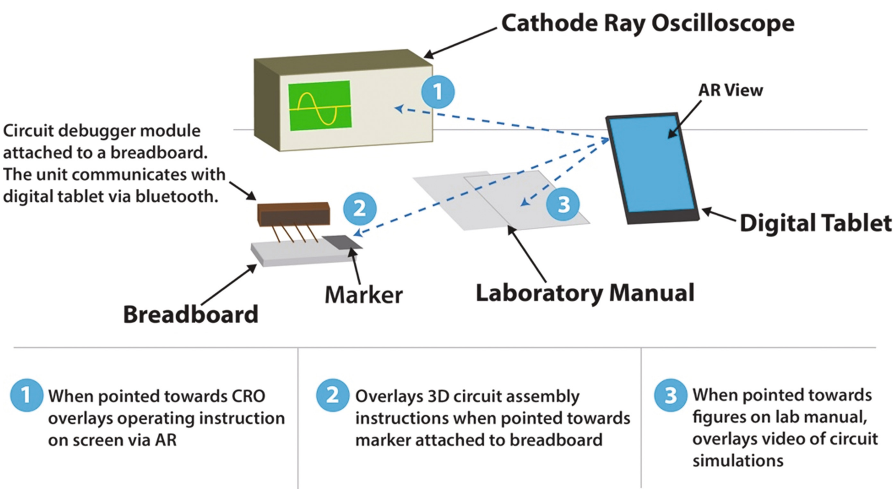

Fig. 3. SLS setup consisting of a smartphone that acts as a mediator of AR and an intelligent breadboard that is able to instruct students during troubleshooting.

corresponding instructions were generated for user. These instructions were provided to user through text-based and voice-based functionalities. Figure 3 depicts overall setup of SLS.

6 Defining Instructional Intelligence and Understanding Automation in Practical Electronics Laboratory

The SLS works on the concept of distributed intelligence [26, 27] to provide automation. The AR module help students relate to various theoretical concepts via interactive videos and 3D graphics to get information regarding operating test equipment like CRO. The AR also helps students visualize circuit assembly on breadboard. By providing this information, the AR is able to "automate" certain aspects of the activity wherein students would have required the help of instructors. Such as, during assembling of physical circuits, students often ask instructors how to arrange different electronic components on breadboard, what configuration of components is required, where should they make electrical connection on breadboard with the IC, and so on. The AR is able to address these issues. Secondly, by providing videos that are contextualized pertaining to a specific experiment and its related task, the AR is able to save students extra effort required to browse through a series of unstructured sea of information available on the internet or to wait for an instructor to come and explain them the concept or working. This way, the AR automates the task of information delivery for students – thus reducing their workload, thereby also reducing the burden of instructors to address the need of each student group in practical electronics laboratory session.

When students face problems with circuit assembly like loose wire connection, power supply issues or wrong connections, the circuit debugger senses these mistakes or errors and sends instructions to students via the smartphone. These instructions provide feedback to students depending on the level of mistake or problem being faced. For this, the possible mistakes and experimental procedures, and the required set of instructions to rectify these mistake or error are stored in a database. Various task-flows of different practical laboratory experiments need to be constructed for this. A group of such task-flows combined together provide decision making capability to the system to provide suitable set of instruction to students. For example, if a mistake is sensed by the debugger system, it checks the level of understanding required to instruct students from the decision-making module and based on that provides the required output. Figure 4 represents a block diagram partly conveys how instructional intelligence is being embedded into the debugger system.

The input or data layer contributes towards first degree of intelligence (1-DOI) and is mainly responsible for sensing and computing functions. The user interaction in this layer are mostly tangible – example, assembling circuit on breadboard that is attached with the debugger module. Thus, it is a tangible user interface (TUI).

Developing effective instructions and learning content corresponding to task-flows and errors is the second degree of intelligence (2-DOI). Designing rich learning experience and interactions with the system is third degree of intelligence (3-DOI). Based on these premise, the SLS prototype was developed which been discussed in previous sections. Study [15] further places an elaborate discussion on designing AI for smart devices based of students' feedback.

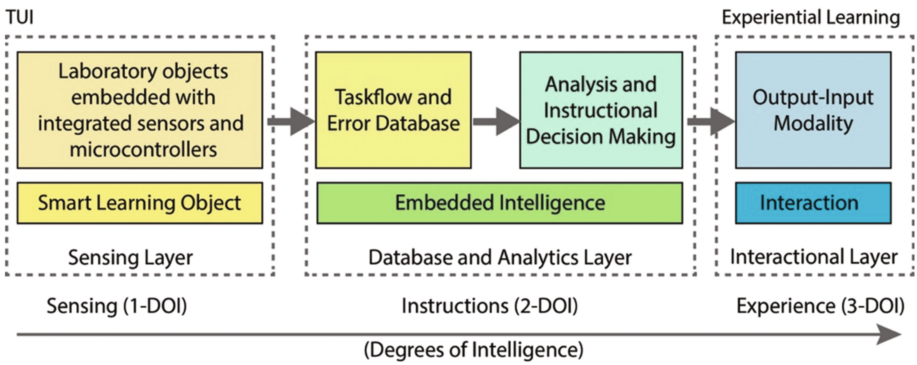

Fig. 4. Block diagram representing increasing degrees of intelligence embedded into learning system as a part of making automation intelligent.

The following pseudo-code partially defines the instructional intelligence embedded for the purpose of circuit debugging.

```
Algorithm circuit-debugging is
Input: Check connection on breadboard

Output: Voice and text based instructions

for each circuit connection on breadboard do
    scan for loose connections

if there is no mistake in connection on breadboard do
Output: Good work

else if there is a mistake in connection on breadboard do
check database for required instruction for each mistake
Output: Specific instructions
```

The intention is to embed intelligence into SLS so that it is able act as a human tutor to assist students in lab sessions.

7 Analogy of SLS with Human Tutor

In a conventional, students when they make mistake during circuit assembly or while facing difficulty in understanding the theoretical concepts, rely on lab instructors or peer to help them. The tutor helps students either by pointing or highlighting mistakes made during circuit prototyping or explaining the underlying theory behind the experiment.

The proposed SLS can be considered analogous to a human tutor. When students prototype circuits on a breadboard, it is mostly testing that is required to debug circuits. This requires a lot of effort and mental demand. Consider arrangements of electronic components and wires on a breadboard to be the syntax – i.e. the structure of the circuit and breadboard to be the console, intelligent breadboard acts a debugger – a task which is generally performed by taking help of human instructor in lab. The output modalities, such as AR or voice-based interface act as mediums to inform users regarding these errors – similar to the way instructors teach students. Hence, if any errors like loose wiring between rows of breadboard, wrong connections or varying voltages are sensed, they fall under syntactical errors and informed to user. Thus, efforts required in testing and debugging the circuits by users can be reduced. The SLS is, in this manner, able to automate several trivial processes of human tutoring.

8 Influence of SLS on Student Engagement in Practical Electronics Laboratory Sessions

This section presents the results of prototype evaluation conducted amongst student participants to understand the influence of automation on their work and overall classroom dynamics. For this, the SLS prototype was demonstrated to the participants and various functionalities were explained to them. The only limitation was that SLS was a lightweight prototype and could not be used for a full-scale testing for summative evaluation. Therefore, scenarios and mock-ups [23] were used during the evaluation along with SLS prototype to explain users how the end product will be like along with all its features and functionalities. Scenarios play an important role in evaluation of novel systems that are under constant design and development phase as the technology is often not well understood by developers [28]. Both qualitative and quantitative aspects of HCI were also utilized to overcome the limitation of evaluating a lightweight prototype. The study relies on qualitative aspects, such as semi-structured interviews and open-ended questionnaire responses, to gather experiences of students and instructors to inductively derive understanding about the influence of automation on users and their work environment. The quantitative studies focus of the usability aspect and assess learners' satisfaction. Both quantitative and qualitative aspects complement each other to capture broader aspects on the utility and usefulness of automation technology in practical laboratory scenario.

8.1 Qualitative Analysis of the Responses

Responses were collated from student participants on open-ended questionnaire (N = 24) regarding the use and influence of SLS on their learning experience and task in a practical electronics laboratory. The responses were analyzed using the method of content analysis [29]. Laboratory instructors ($N = 2$) were also interviewed to describe their opinion regarding the effect of SLS in practical laboratories: Will it be helpful to them? How will it influence students' performance?

Table 3 presents qualitative responses of student participants who filled our open ended questionnaire. These responses highlight the attitude of students towards SLS and the concerns arising regarding its usage on dependence of students on such systems. The participants have been coded P1 to P6 and their responses have been presented in the next column. For the sake of brevity, 6 responses (out of 12 received) have been described in the table. Participants reported the system to be very helpful and showed a positive response towards accepting the SLS if it is made available to them. The participants also highlighted that the system would help them learn independently at their own pace.

From the responses, it can be inferred that automation techniques such as SLS can help reduce the amount of effort students require in laboratories thereby making their work easier. There were certain concerns raised by the participants regarding how such systems might lead to overdependence on automation technology – and if it would hinder with the overall learning? While concerns like this are always there with any new technology, the upside always weights the downside. Studies [30] have shown that

Table 3. A excerpts from a few students' responses regarding SLS

Participant	Responses
P1	*"This smart learning system is easy to use and makes our work easier."*
P2	*"This will be very helpful for our learnings and will be more comfortable. It will make experiments funny and more interesting."*
P3	*"... it is very useful in lab class... Improve the durability while working in the experiment and give the best help..."*
P4	*"It will definitely reduce the efforts on our side, but won't we grow dependent on this system?..."*
P5	*"Very smart and cool system, but make sure you get all possible errors and solutions coded in the program"*
P6	*"... it is very helpful not only for the experiments but for the basic knowledge we need to understand for the experiments. ... it will be fun."*

almost 78% of students face frustration in laboratories due to equipment issues and inability to understand practical experiment. Considering that automation will be able to reduce such factors leading to frustration – we posit that it will only improve the learning experience.

The findings of the qualitative study can be verified from the quantitative study that access various usability aspects and learners' satisfaction, as describable below.

8.2 Usability Testing and Hypothesis Validation

Usability testing and evaluation of SLS prototype was conducted amongst (N = 95) randomly selected undergraduate students, (Mean_{age} = 18.33, SD = 0.62) comprising of 23.1% females and 76.8% male participants, see Fig. 5. All students were undergoing practical electronics laboratory sessions as a part of their coursework. The aim was to enquire what effect will SLS have on learners' satisfaction and will students find the system useful enough to be adopted as a learning aid.

Fig. 5. Usability testing in progress

The participants were asked to interact with the SLS and explore its functionalities. After interacting with our SLS prototype in practical laboratory sessions, the participants were asked to fill a 15-item questionnaire relating to Perceived Learner's

Satisfaction (PLS) scale. The participants were asked to indicate their agreement or disagreement with the questionnaire items on a 7-point Likert scale where 1 = strongly disagree and 7 = strongly agree. The questionnaire on e-learner's PLS was adopted from Wang [31] and modified for our study by introducing features for SLS. The questionnaire used learner interface (I), content (C), personalization (P), and, peer collaboration (L) to measure learner's satisfaction. Questionnaire items were modified to encompass the functionalities of SLS in terms of its interface, content and the degrees to which it would support collaboration amongst students in practical sessions. Participants willingness to continue the usage of SLS was also included.

A 4-item perceived ease of use (PEOU) [32] scale, single item perceived usefulness (PU) [32] scale and a 2-item relative advantage (RA) [32] scale questionnaire were also administered to participants after their interaction with SLS. Table 4 presents descriptive statistics obtained from the questionnaire responses.

The participants showed a good willingness to continue usage of SLS (M = 6.13, SD = 1.11), as rated on a 7-point Likert scale. In general, the users found the SLS prototype easy to use, usable and liked the learning content provided by the system.

Table 4. Descriptive statistics of students' rating PLS, PEU, PU, RA (N = 95)

	Mean	SD	Likert scale
Perceived learner satisfaction	5.86	0.13	7-point
Perceived ease of use	4.37	0.10	5-point
Perceived usefulness	4.34	0.69	5-point
Relative advantage	4.35	0.02	5-point

8.2.1 Hypothesis Validation

It was hypothesized that a positive relationship exists between learners' satisfaction and the reuse intention for SLS. To test the hypothesis, a Spearman's rho correlation analysis between the total score of PLS questionnaire items (I, C, P, L) and the sum of criterion questions was accessed, as per the guidelines provided Wang [31]. Spearman's rho correlation shows a statically significant positive relation, $r_s = 0.751$, $p = .01$, thereby validating the hypothesis.

8.3 Effect of Automation on Practical Laboratory Instructor's Task Simplification

Students in practical laboratory sessions are often dependent on instructors for getting face-to-face assistance regarding the experiments. However, in case of large batches in laboratory sessions, this face-to-face interaction often gets limited to very few student groups as the instructors often need to spend a lot of time with (sometimes) trivial debugging issues in one group. This often leaves few other groups, that require more assistance of instructors, waiting in queue for long time durations. Sometimes, these groups are not able to receive the attention of their instructor at all in a time restricted laboratory session. This causes burden on the instructors in the next practical session to help the lagging group catch up with the rest of the class. Further, as the instructor is often too busy to be available for each group at the same time, students have to rely on internet-enabled smartphones as an alternative for seeking out information regarding procedures of practical experiment being conducted by them. This causes the students to lose a lot of time searching for desired information in a time-limited practical laboratory session [33]. Since the information available on the internet is unstructured, unlike instructor's knowledge, it also distracts students from the practical experiment. All these issues lead towards lack of uniformity and quality of instructions that cause less teaching and learning satisfaction in instructors and students.

In addition to the aforementioned difficulties, issues also arise relating to lack of working equipment or proper infrastructure – often in institutes with paucity of resources. Such limitations lead towards constraints in human resources and lack of knowledge transfer capabilities for students. The interviews with instructors highlighted that the use of SLS in laboratories will be very helpful in minimizing such constraints. The following response from instructors elicits various aspects where automation technology such as SLS can be helpful:

Responses regarding assembly of circuit

> "Students often make mistakes with breadboard. They are not able to understand how to use the rows and columns properly. … I think this AR would be helpful to students in showing how they can connect the circuit properly…with a few improvements, I think this app can be useful…"

> "I think this circuit debugging is very good….it is one of them most difficult things in labs…it will really reduce the effort and save time…"

Response regarding operating test equipment

> "…. I really liked the idea of using AR for CRO. It is one of the most difficult equipment in lab. Not only students, sometimes we also find it difficult to stop the flickering…there are many faulty probes also…but showing how the CRO works will be great! If you can also add a video showing how CRO works it will be very helpful…"

Response regarding referencing

> "I think this video feature is very helpful…students mostly prefer videos over books…this will definitely help them a lot"

Response regarding SLS addressing resource constraints issues

> "Many institutes do not have the resources or large number of lab instructor that can attend all students …. This application can be really helpful in those institutes…."

> "How does it work? Does it require Internet? … I think this application will be very useful in areas where they do not have the Internet facilities….students can learn on their own…"

The instructors also highlighted that while such systems are helpful, they pointed out that there would always be a need for supervision in practical laboratories. It was also suggested that while such systems are good for addressing need of several students who require less help in laboratories, students who often find it difficult to work with experiments need continuous guidance of instructors. From these insights, it can be inferred that proving automation ability in practical electronics laboratories can help distribute instructor's workload and help them direct their attention towards those group of students that require help. For issues that are trivial in nature, SLS can help assist students with them. Thus, such systems can also save time of both instructors and students. The responses also indicate that SLS can help address issues pertaining to lack of infrastructure and paucity of human resources that hinder with teaching and learning satisfaction of instructors and students.

9 Human-Work Interaction Design Heuristics for Automation in Practical Electronics Laboratory

The study presents some interesting observations into workspace related and human-centered issues surrounding complex learning environment of practical laboratories, as depicted in Fig. 6.

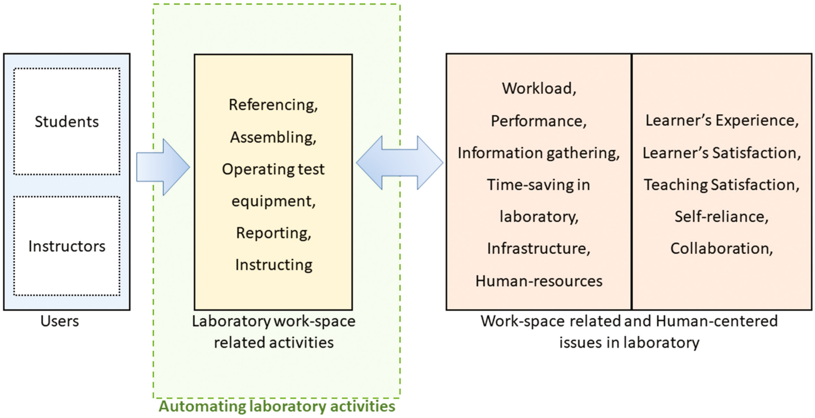

Fig. 6. Workspace and human-centered issues in practical laboratory

A useful and usable automation system should be able to address these issues in such a scenario. Based on this premise, an initial attempt has been made towards developing heuristics for designing an automated system for practical laboratory environment and are described as follows:

- **Task augmentation through automation:** Users (students and instructors) in practical laboratories are required to perform multiple tasks such as assembling of circuits, referring to laboratory manual, operating equipment and instructing. This leads towards an increase in the extraneous cognitive load of users [34, 35]. The automated system should be able to augment each of these individual tasks – thus leading towards reduced cognitive loads.

- **Designing instructional content for students:** Students mostly rely on their laboratory instructor's experiential knowledge for getting information and understanding about the practical experiment. The designed automation should encapsulate instructor's experiential knowledge (or tacit knowledge) that can be delivered to students through different modalities, such as augmented reality or voice-based instructions. Techniques like think-aloud sessions and hierarchical task analysis can be utilized for capturing and segmenting instructor's knowledge while they perform an experiment.
- **Mode of instruction:** Voice-based instructions were reported to a useful feature for independent learning that takes place individually or outside of the laboratory sessions. During laboratory sessions, students preferred visual and text-based instructions. Students also suggested including more language options for voice-based instructions in the application as they feel more comfortable getting inputs in their native language.
- **Inbuilt embedded content:** The AR application should be a stand-alone fully functional medium of instruction for students without requiring the need to connect to the internet for downloading content data. This ensures the usability of AR application in places without the internet connection.

10 Future Work

The paper presents a step towards designing smart learning systems capable of reducing students' workload and improving their engagement while learning in practical laboratory. The system presented further requires summative assessment utilizing robust prototypes with well-designed content. Such assessment will be useful in understanding aspects like quality of training and level of information recall by students. In addition, assessments are also required to be carried out in terms of understanding the effect of the proposed system on instructor's workload.

11 Conclusion

The study presents a novel automation tool, SLS, for use in practical electronics laboratory session utilizing the concept of smart objects [6] and AR. It shows that such automation techniques can help create engaging learning experiences for students and at the same time reduce the burden of laboratory instructors. The prototype presented in the study is based on the idea of distributed intelligence that helps automate several tasks and augment students' ability to gather contextualized information and instruction. The study also shows that it is possible to augment and automate existing laboratory objects, such as breadboard, and embed intelligence into it to help provide better instructional capabilities to the students.

From the study, it can be inferred that creating automation in complex learning environments such as educational practical electronics laboratories also help save time of both instructors and students and make learning easier.

Overall, the paper contributes towards understanding design of a system that supports users through the use of technology in a complex work context of educational laboratory and is concurrent with the theme of improving human-work interaction design.

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