Fig. 1. System architecture of AR system.

Further, the task was tested under three different learning interfaces: (1) a paper-based document that serves as a control group against AR systems, (2) a traditional AR-based training system, and (3) an enhanced AR-based training system that was developed by applying design principles that encourage meaningful learning.

3.3.1.1. The paper-based document. The paper-based document (see: 10.17862/cranfield.rd.24079371) contains all information about the electronic system and its components. It also consists of a step-by-step information in the form of textual instruction and pictures to complete a wiring task.

3.3.1.2. The traditional AR-based training system. This training system replicated most of AR systems used for learning the assembly tasks which include textual information, graphical objects (e.g. arrow) for pointing certain objects, and videos. Users were initially presented with an overview of the electronic system and its all components using tooltips and graphical arrows (See Fig. 2(a)). To acquire skills in wiring the system, assembly instructions were presented step by step on top of the workspace in the form of texts as well as videos which describe the task and how to do it (See Fig. 2(b)). The users can pause and play the video as much as they like and proceed to the next step.

3.3.1.3. The enhanced AR-based training system. The enhanced AR-based training system was similar to the traditional one regarding the contents. However, it had voice cues (multimodal information) that gives additional context and information to the user. For example, during the unscrewing part of the power supply, the voice cue gives additional information on how to perform the task: "To loosen the screws, do two or three counterclockwise turns with the screwdriver on both screws". It also included common mistakes and consequences panel after each step to enable the user to grasp the significance of their actions and increase the understanding of the system behavior (projection of the given states and their consequences) as shown in Fig. 3.

3.3.2. Experimental procedure

To examine how different methods of learning affect users in understanding the task and reusing the acquired knowledge to a different situation, this study assessed independent groups of users (between-subjects test) who were assigned to each learning method to learn the same task. Each participant was asked to fill out a demographic questionnaire (see: 10.17862/cranfield.rd.24079371) which includes electronical and augmented reality background questionnaire to check whether they had done some tasks related electronics system and if they were familiar with the use of AR prior to the experiment. After that, each participant was given a questionnaire with questions related to the studied wiring task to test their initial knowledge about the system.

The test consisted of questions about the identification of different components they would use during the task and about general knowledge given during the experiment. Following this, a total of thirteen participants were involved in this experiment where four people were assigned in traditional AR group, five people in the enhanced AR group, and four people in the paper-based document group. They were all students (Male = 6, Female = 7) and aged between 25 and 35 years old. Their knowledge about electronics was balanced across the groups (See Section 4.1). The test was graded over 11 questions and was also given after they finished the task to measure the amount of information they learned after going through a training (short term retention test). One week later, each participant was assessed again with the same questionnaire to test their capability to remember what they learned (long term retention test). The duration of a week has been used in many studies for memory retention test [16,26]. Furthermore, participants were not told that the questionnaire would be the same after one week. Existing studies that measured task learnability typically focused on

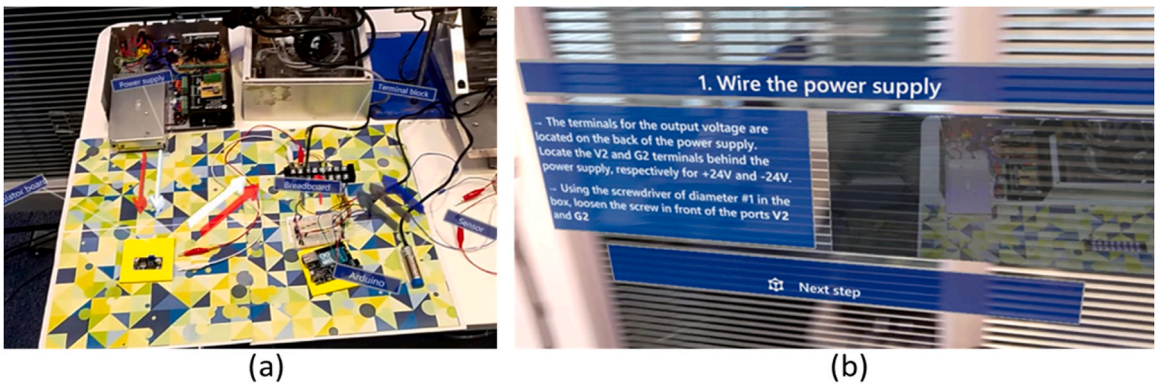

Fig. 2. Traditional AR-based training system: (a) the overview of the electronic wiring system, (b) assembly instructions in the textual form and video.