Learner versus System Control in Augmented Lab Experiments

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Abstract
We present a user study of the mock-up for a learning environment on electro-mobility, based on tracking of physical interactions and projected augmentation. We discuss observations and interviews with participants that were led through a task scenario. Our insights highlight user needs in an educational context. There is generally high acceptance for augmented reality in experimentation environments. On the other hand, there are some essential points regarding user guidance and system concept critical for practical experimental education in schools and universities. We describe the most important areas of decisions for further development. Frequently, these concern questions about degrees of freedom - on the part of users as well as system.

Author Keywords
experiments; mixed reality; education; electro-mobility

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Augmented Reality has recently gained a lot of attention in education as a promising concept [2, 9]. But its use is still in its infancy, although it can add value to traditional teaching and has the potential to revolutionize education [1, 8]. It can extend the real environment

Small schematic of areas on the board

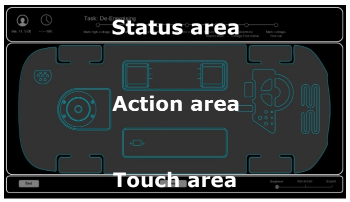

Figure 1

***Status area* (at top)**: Users see their user name, time of use and task chosen (e.g. de-energising) and steps.

Action area (middle of board): shows the top view of a car in schematic representation; equipped with real components of an electric car (motor, 12-volt battery, partition plug). Users see a description of components and respective tasks, plus feedback (help support).

T*ouch area (lower part of board)*: buttons to interact with and control the system, e.g. 'next' or 'end'. Selection menu for learning level (beginner, more advanced learner, expert). This can be changed during interaction. In our mock-up, all buttons are projected.

with augmented information that can become interactive, visualize the unseen, bring things to life and into the classroom that would otherwise be too expensive or impossible. In addition, it can make learning more fun, engaging and interesting. There are normally no real consequences if mistakes are made during skills training in terms of dangerous and hazardous work. Thus, AR can support independent, active and meaningful learning [1, 2, 5, 8, 9].

Educational AR applications should not be seen as meant to replace established teaching methods, but should be combined with these to form a modern support tool [7]. Although many educational and training AR applications have been developed [7], AR's potential and pragmatic use have just begun to be explored and utilized. There are a lot of open questions on its use in education and training, as well as development and evaluation, e.g. concerning its integration in traditional learning methods, efficiency, costs effectiveness, consideration of didactical and learning theories as well as usability, maintenance, etc. [5].

In this paper we concentrate on the learning domain of electro-mobility (i.e. electric vehicles, how they work and their maintenance/repair) and present a study of a non-functional prototype / mock-up. To our knowledge no educational AR systems for this topic exist yet. In our approach we mainly focus on augmentation via in-situ projection to enable the use of real components and contextualized information provision. In the following, we describe the concept for our electro-mobility learning system, as well as the current mock-up. Then we present our user study and findings. Finally, we discuss our insights from the study and raise questions for further research.

Background

Under the environmental protection label, more and more electric cars come on the market. Knowledge about electric vehicles thus gains importance for training and vocational education. Because of its growing importance, this domain was chosen as case study within a larger project focusing on developing augmented real-physical laboratory classrooms experiments. A general problem in vocational training is that learners often lack prior knowledge and learning motivation. According to the teachers we interviewed for our project, learners often do not (or not properly) prepare in advance for class or conduct follow-up revision. There is a need for new didactic-technological approaches to support practical hands-on learning, train real work situations and raise motivation levels.

To address the above issues, in the context of our project ELIXIER, an electro-mobility learning system is being developed, which integrates an interactive AR learning environment, integrating sensor technology and actuators for lab-based experiments.

The Envisioned Electro-mobility Learning System

The final electro-mobility learning environment will assist teachers and learners in every phase of learning, including preparation and revision. It will consist of (1) an augmented reality lab-bench for experiments, using sensors, actuators, tracking- and projection system, (2) a web-based infrastructure that connects and synchronizes all learning steps and elements of the overall system, and (3) a simulated photo-realistic experimental setup with 'interactive screen experiments' (ISEs). Learners can access the ISE with a personalized account from outside the classroom (on tablet or computer) to prepare and revise experiments. Within the ISE,

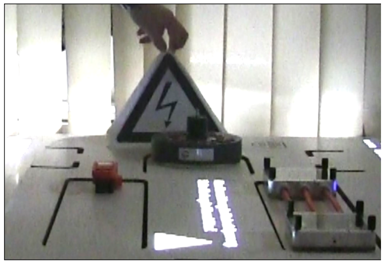

Figure 3. Placing the warning triangle

Figure 4. Turning the ignition key

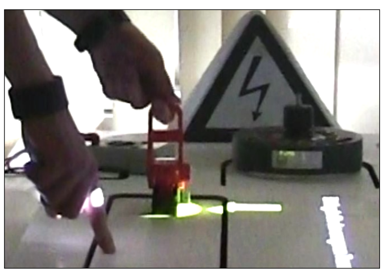

Figure 5. Unlocking the partition plug

virtual elements can be moved with drag and drop to simulate a real experiment via stop-motion, made interactive via JavaScript [4]. In the current paper, we focus on aspects concerning only the experimental lab-bench component.

This augmented lab-bench is to provide students and teachers - depending on learning level - with tutorial assistance during set-up and experiment. It will provide supportive information, explanations, and instructions, or sensor values next to a component. For the electro-mobility scenario, it may also visualize the otherwise invisible energy flow. Teachers will be able to define new tasks and test formats, or to simulate errors, since error tracking, troubleshooting and fault removal are a core theme in vocational training. Altogether, the augmented lab-bench will expand current lab workbenches via augmentation and tracking, using real components, smart sensors, camera and projector. Standard instruments and tools can be used, such as a voltmeter. Whenever the use of original components would lead to a “black-box” effect or is prohibited for safety reasons, didactical prepared components will be used.

The Electro-Mobility Mock-up

In this paper, we describe evaluation results for a non-functional prototype (also referred to as a ‘mock-up’). The mock-up is placed on a slightly inclined board. A projector is installed above the board, creating the visual augmentation (see Figure 2). There are three main areas (see side column, Figure 1).

The selected task for our evaluation was ‘de-energising’ (Figures 3 to 8). The aim is to de-energise the car before starting work. Participants had to carry out the following steps: 1. mark high-voltage of the car by positioning a yellow warning triangle next to it, 2. switch off ignition by turning the ignition key, 3. disconnect two bridges from the 12-volt battery and measure its voltage, 4. put on protective gear (gloves, glasses), unlock the partition plug and secure it against reactivation by placing a green cover over the access, 5. measuring the current voltage at the connection E-motor, and finally 6. mark the vehicle as de-energised and voltage-free by removing the yellow warning triangle.

Figure 2. The non-functional Electro-mobility prototype

The mock-up is non-functional; this means all interaction steps for our user study were simulated via slides projected onto the board (see Figure 2) and the moderator changed the slides in response to user actions. A few potential user errors had been integrated into the interaction flow. All explanations, instructions and support information were presented as text.

User Study

Our aim was to gather feedback, in particular on planned functionality, instructions, help and support as well as overall design. We further wanted to gain in-

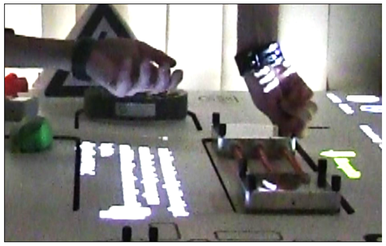

Figure 6. Removing the plexiglass cover of inverter connection box.

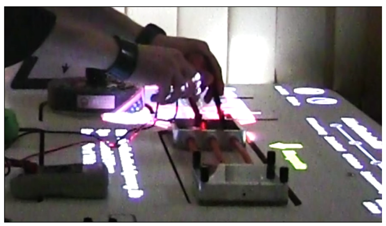

Figure 7. Voltage Measurement.

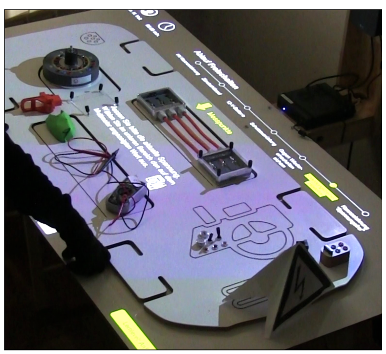

Figure 8. Removed loose parts and additional tools on the table.

sight into how prospective users would interact with the system, their needs and requirements. The evaluation took place in early 2017 at the Bauhaus-Universität Weimar. During the study, two researchers were present - a facilitator and a note-taker. Each session took about an hour. First, participants were led through the task scenario described in the previous section, with the facilitator controlling the projections in response to user actions. Participants were instructed to think aloud. All sessions were recorded on video. After the task, participants were questioned in a guided interview, with closed and open questions regarding functionality and usability. Closed questions were answered with yes/no, or on a five-point Likert-scale. 10 people aged from 23 to 37 (Ø 28 years) participated in our study, all male, and either student or university staff. One had training as car mechanic, the others had no specific knowledge of electro-mobility or electric cars.

Observations from the videos were sorted into categories according to the scenario steps. The interviews were transcribed, split into topics, i.e. usability. We compiled recommendations on general usability, suggestions for extension of the system and special features for educational purposes that should receive particular consideration in the next design iteration.

Evaluation Results

Participants rated using the mock-up as easy (9 of 10), easy to learn (10), and largely self-explanatory. Instructions were clear, giving step by step guidance. Participants could imagine that most people would learn to use it quickly (M=4; SD=0.82) via learning by doing. They also found it easy to find information (M=4.2; SD=1.03). But the system could provide more information, and do so in context. Furthermore, instruction was requested on where to place parts that had to be removed (e.g. a key, a cap taken off) from the demonstrator. According to most participants, error messages were clear (M=4.4; SD=1.07) and helpful for fixing errors (M=4.1; SD=1.37). However, some found error descriptions not clear enough. Thus error messages and support for troubleshooting should be improved.

Altogether, participants were satisfied with the system (M=3.5; SD=0.71) and rated the system as useful for learning (M=3.9; SD=1.1). They commented positively on the augmentation and close relation to practice, and believed this supports practical learning. They liked that users have to carry out all steps by hand, physically manipulating things. Furthermore, they liked that real and virtual elements are connected, the use of authentic tools (e.g. voltmeter), and that tasks are placed in dedicated areas of the board. However, they thought the system is still too theoretical and would currently only support an optimal order of interactions, not catering for possible user mistakes and questions. Further, they emphasized the three level modes and liked the status area overview (figure 1) showing the progress.

In general, the system was considered consistent (M=4; SD=1.33) and not over-complex (M=1,8; SD=0,42). However, participants sometimes felt overwhelmed, especially at the start when a lot of information appears all at once. They found it not obvious where to focus attention. Furthermore, it was often not clear which elements are active and can be interacted with, as colour-coding of buttons and information areas was unclear. Moreover, projection overlaps and shadows or inaccuracies need to be improved. Findings indicate that attentional control should be improved and colour-coding reconsidered.

General decisions should be made on system design, e.g. whether all components are real or none. Moreover, all parts on the board need to be explained, as currently it is not clear why some components are present, e.g. the engine. It is also necessary to convey straight from the start that the representation in the board center (action area) shows the top view of a car (none of our participants realized this initially). This could be done with an intro video and projections that, for instance, visualize head and rear lights and driving tires. Moreover, there should be better support for how and where to measure something, e.g. with spotlights.

Main Findings & Discussion

1. Attention-Steering. During use of the mock-up, participants frequently did not know where exactly to focus attention or what to focus on. This was especially the case when different components were illuminated or when information was simultaneously projected. Thus, one of our main findings is that attention control must be improved. We propose the following: individual items should not appear all at once, but in succession or in semantically related groups; a spotlight-metaphor or visual zoom-effects can be used for individual components; individual areas and texts should be highlighted visually or via different colors. Besides that, attention can also be directed by means of auditory indications (sounds, noises).

2. Room for exploration. The participants criticized the lack of exploration opportunities (or user control). Users currently have to follow instructions and to adhere to the default task steps. Thus, interaction is very similar to teacher-centred teaching. Participants felt that learners need more freedom, to be able to do everything possible in reality, and to figure out things by themselves. The system should then react appropriately. Strict experimental procedures should be softened, providing more room for exploration. The question is: *how can such an exploratory approach be supported when the experimentation procedure is established?* One possibility for this is context-sensitive support and help. Here the question is: *how can this be technically realized during experimentation and done in a didactically meaningful way?*

3. Contextual information and magic mode. In general, the study participants would have liked the opportunity to get help during interaction, more information and further explanations. But instead of a ubiquitous help button, they preferred getting help and information in context, for the step worked on. This could be realized with a knowledge base, or a kind of "magical lens". Another idea was that the user gets contextual information or help when they point to a component or use an additional monitor (e.g. a tablet). Moreover, a "magic mode" was proposed, to visualize invisible phenomena (e.g. current flow) when the user activates it. Therewith a deeper understanding of processes and procedures should be created.

4. How much error feedback? An open issue is how error feedback should be designed to support learners, while not directly showing mistakes or prescribing what to do in troubleshooting. Here learning-theoretical considerations compete with usability principles [3]. In education, priority tends to be given to the former.

5. Dealing with physical, loose components. As our participants did not know where to put removed parts, they put them on the board or a table behind them. This creates issues in recreating the default state or risks parts getting lost. This is a very specific issue that arises with tangible interaction systems [6]. We therefore need to provide explicit storage, e.g. a toolbox.

6. Multisensory feedback. Participants desired more sensory feedback during interaction, esp. tactile, visual and auditory. They mainly missed sounds and noises during interaction. Thus, the system could address more senses, e.g. via sound, noises and vibration of different elements, where appropriate and realistic.

7. Intelligent detection of user actions. According to study participants, the system should be more intelligent, i.e. adapt, so that the user does not have to confirm each input/action with the "next" button. This could be realized with tracking technologies such as visual markers, interactive projection, gesture recognition or voice control.

Our study has pointed out areas for further research and attention in design, in particular regarding degrees of freedom in learner interaction ('room for exploration' and 'how much error feedback') versus system control. In addition to technical realization of the system architecture, our challenge will be to conceive the digitally supported real-world experiments so that the various teachers in educational institutions consider them useful. Here, the concepts must be adapted to fit with the day-to-day work of teachers at universities, polytechnics and vocational schools and suit educational purposes.

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