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Support for Augmented Reality Simulation Systems: The Effects of Scaffolding on Learning Outcomes and Behavior Patterns

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Abstract— An AR-based simulation system that integrates background knowledge and experimental support (AR-SaBEr) was designed as a learning tool for teaching basic principles of electricity to ninth-grade students. The aim of this study was to investigate how supporting the learner focus on meaningful activities affects behavior and learning performance. The sample was 82 students, who were randomly assigned to two groups. The control group used AR-SaBEr with no support for recommending activities. The experimental group had personalized extra support designed to help learners focus on the subject matters that they did not master. The study found that learners from experimental group showed better learning achievements than those who participated in the control group. Furthermore, learners' behavioral patterns were dependent upon the support received. Learners from the control group were more willing to browse information about activities than to read about the subject before experimenting. Learners from the experimental group browsed activities information prior to carrying them out and read about the subject matter prior to experimentation. The observed behavioral patterns and learning achievements suggest that in augmented reality based simulation environments it is worth providing mechanisms to focus the attention of students on the most relevant topics for them.

Index Terms—augmented reality, behavioral pattern, computer simulations, scaffolding, science learning

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1 INTRODUCTION

AUGMENTED reality (AR) is a technology that enhances the user's sensory perception of the real world with a computer-assisted contextual layer of information in real time [1]. AR has become a central player in the technology landscape since its introduction in mobile devices provided with high communications bandwidth and basic AR browser tools. In the educational arena, the 2011 Horizon Report [2] drew researchers' attention to this emerging technology that enables creating enhanced learning environments in which coexist real and digital worlds in real time [2], [3]. Since then, educational researchers have increasingly explored potential opportunities for teaching and learning of AR [4]. Initial studies devoted mainly to development, usability, and initial implementations of applications have revealed educational values of AR including providing contextualized information, allowing the visualization of invisible phenomena and the interaction with 3D objects in real time, favoring learning cognitive processes, and supporting collaboration activities [5], [6], [7]. Leader researchers suggest that one of the most promising uses of AR in education is to support science learning with simulation activities [8], [9], [10].

The use of AR in education is not exempt from risks, engagement in AR activities can become an obstacle for achieving desired learning goals. Indeed, in a located based AR system devoted to active inquiry, M. Dunleavy et al. [10] report how students were so engaged in the AR system that they paid no attention and lost track of their real environment, whereas the activity required the incorporation of the physical space into the learning experience. They also pointed out that learners were so engrossed exchanging information that they ran out of time and had difficulties completing the activity. A similar problem has been reported by B. Schneider et al. [11] regarding tangible interfaces. Indeed, they claim that tangible interfaces may constrain reflection and abstract thinking by blocking the learner in manipulative activities. Similarly, in a previous work the authors of this study found that although students were highly motivated by experimenting with an AR-based learning environment almost one out of four simulation tasks they made were unsuccessful and learning effectiveness was rather small [12].

On the other hand, often the use of computer simulations in discovery learning has been ineffective in improving learning processes and outcomes [13], [14], [15], [16]. Consequently, some researchers have studied the difficulties that learners might encounter in the discovery learning process [13] and proposed mechanisms to overcome

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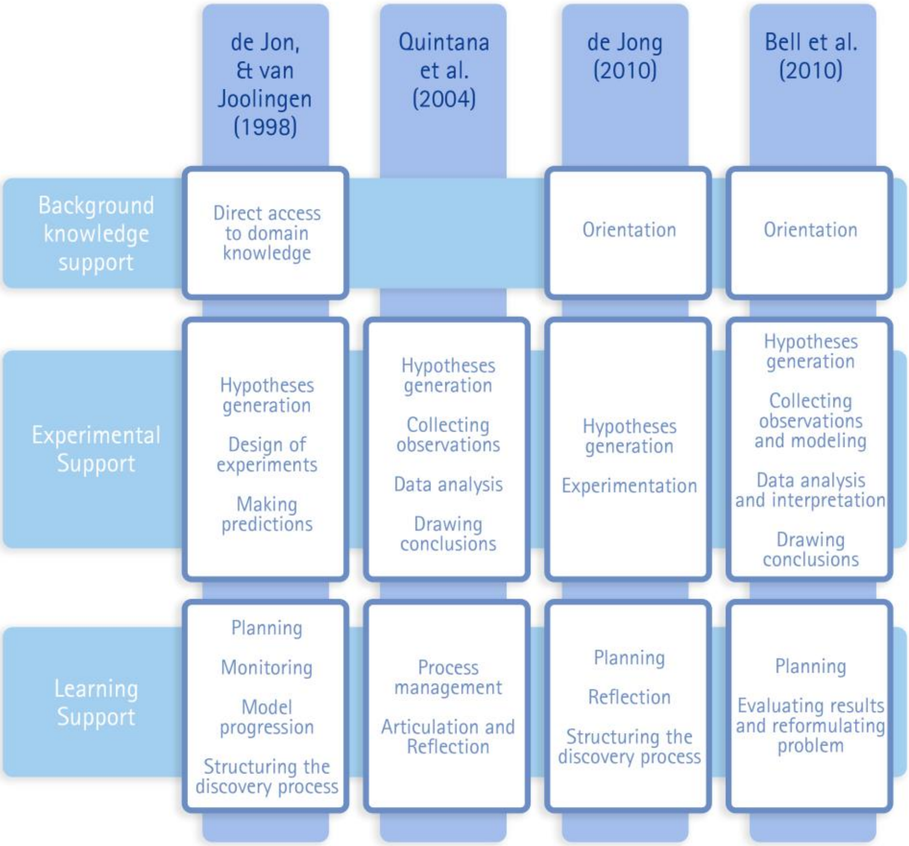

	de Jon, & van Joolingen (1998)	Quintana et al. (2004)	de Jong (2010)	Bell et al. (2010)
Background knowledge support	Direct access to domain knowledge		Orientation	Orientation
Experimental Support	Hypotheses generation Design of experiments Making predictions	Hypotheses generation Collecting observations Data analysis Drawing conclusions	Hypotheses generation Experimentation	Hypotheses generation Collecting observations and modeling Data analysis and interpretation Drawing conclusions
Learning Support	Planning Monitoring Model progression Structuring the discovery process	Process management Articulation and Reflection	Planning Reflection Structuring the discovery process	Planning Evaluating results and reformulating problem

Fig. 1. Types of support to overcome difficulties associated to scientific discovery in computer simulation environments.

these problems. Their recommendations encompass two major guidelines: the exploration of diverse media to deploy simulation tools, and the integration of instructional support into discovery learning activities [13], [17], [18]. Therefore, AR technology might be useful to support science learning with simulation activities provided that instructional designers capitalize psychological affordances of this technology to achieve the effectiveness of and learners behaviors while using AR-based learning environments [19], [20].

As an effort to shed some light on how to learners using AR exploratory environments can discover and build knowledge via experimentation, Section 2 reviews the strategies used in web-based simulators to overcome the difficulties that hinder the construction of conceptual models of scientific phenomena. Based on the theoretical foundations of Section 2, an AR-based simulation tool is presented in Section 3. The tool was designed to explore the effect of scaffolding support strategies in the behavioral patterns of students who interact with the AR-based simulation environment, and to assess the learning effectiveness of the environment for learning basic electrical principles. The research method followed is presented in Section 4, the results and data analysis are exposed in Section 5 and finally, the discussion and conclusions are presented in Section 6.

2 SCAFFOLDING IN COMPUTER SIMULATION LEARNING ENVIRONMENTS

T. de Jong and W. van Joolingen [13] classified the difficulties students found to construct the conceptual models of scientific phenomena into five categories: (1) problems to recall relevant domain information; (2) difficulties in generating and adapting hypotheses; (3) problems designing experiments that provide information for deciding whether the hypothesis is valid or not; (4) difficulties in data interpretation; and (5) problems regarding the regulation of the learning process. A number of studies have been conducted to overcome these problems by assisting learners with scaffolding mechanisms [13], [17], [21]. From the evidence collected, three types of supports can be identified: (1) background knowledge support to provide the domain knowledge related to the simulation; (2) experimental support to assist learners in the core processes in scientific inquiry; and (3) learning support to help learners to perform discovery activities in a structural and systematic way (see fig. 1).

2.1 Background Knowledge Support

Background knowledge support has been recognized as relevant because insufficient background-knowledge may result in an inability to make hypotheses, the design of inconclusive experiments or drawing incorrect conclusions [8], [22], [23]. Researchers have provided background knowledge taking advantage of the technological interfaces supporting the simulation based learning activities. For instance, in web browser based environments, background knowledge can be directly provided through hypermedia links that act as online hypertext dictionaries [23] or through the activation of prior knowledge through direct questions to learners [24]. The unique immersive affordances of 3D virtual worlds can be used to provide in-worlds documents as in the Virtual TEAL World, an interactive and collaborative multi-user virtual world for physics learning activities [25]. Just-in-time access to knowledge can be provided in augmented reality based simulation environments by triggering knowledge information in location based [6] or in marker based augmented reality environments [12]. Regarding AR-based simulation systems in general and those that use tangible objects in particular, it is also beneficial for learners to see instructions integrated with materials to be manipulated [26].

2.2 Experimental Support

Experimental support is intended to help learners to conduct systematic and valid scientific experiments [21], [24]. The treatments developed by researchers encompass a broad range of studies which support the processes for hypothesis generation, scientific experimental design, manipulation of variables, and inference of reasonable conclusions. Scaffolding for hypothesis generation has included templates to formulate syntactically correct predictions [27] or to if-then rules to establish relations between variables [28]. The support provided for experimental design has been based on a range of hints such as "vary only one variable at a time" [21]. Regarding the manipulation variable treatments, studies have focused their efforts on providing tools for collecting, organizing, and visualizing data [29], [30], [31]. Finally, to help learners draw conclusions, the existent supporting tools provide mechanisms for inspecting data in different ways [21], [24].

2.3 Learning Support

By providing learning support students can focus on the principles behind the results rather than become distracted by superficial aspects of the learning activities [21], [32]. Learning support encompasses measures for (1) planning to guide learners through the discovery process; (2) monitoring to help learners to reflect on their progress in relation to their inquiry goals; and (3) structuring the discovery process to guide learners to choose the most relevant and productive tasks [13], [21].

Planning in the inquiry based instruction involves, first, the formulation of hypotheses, and, second, the establishment and implementation of strategies to prove or refute the hypotheses. For example, Co-Lab includes the Process Coordinator planning tool for guiding learners through the stages of the learning process by specifying a series of goals and subgoals to accomplish [28].

Monitoring has been mainly supported by reflective prompts that are proven to increase the self-awareness of the learning processes, and assist learners in connecting new insights with learners' mental models [8], [22].

Finally, software tools can help learners to structure the discovery process by decomposing tasks and by guiding them through key components of the learning activities [33]. Another way of structuring tasks is made by providing explanation guides or by providing the descriptions required to construct products [21]. Platforms such as nQuire divides the discovery task into eight steps helping students to decompose problems which can help guide what actions to take, their order, or necessary aspects of work products; Co-Lab includes the so-called model progression, aiming at reducing the cognitive complexity of the learning process [28], [34].

Experimentar con los factores que influyen en la resistencia.

RECUERDA QUE PUEDES USAR EL ÓHMETRO O UN RECEPTOR CON LA PILA. CUANDO ACABES PULSA...

¿Cuál de las siguientes afirmaciones es cierta?:

A mayor longitud, mayor resistencia y a mayor grosor menor resistencia

A mayor longitud, mayor resistencia y a menor grosor menor resistencia

A menor longitud, mayor resistencia y a mayor grosor menor resistencia

A menor longitud, mayor resistencia y a menor grosor menor resistencia

Fig. 2. AR-SaBEr's mechanisms for the experimental support: (a) simulation goal; (b) tools to measure; (c) tools for visualizing, and (d) drawing conclusions.

3 AR BASED SIMULATION LEARNING APPLICATION

AR-SaBEr is an augmented reality simulator constructed by the authors of this study; it was designed with the aim of introducing ninth-grade students to the basic principles of electricity. The simulator conforms to the Spanish secondary school physics curriculum, and provides both reading materials and AR-based simulations about: (a) the concepts of electric current, voltage, and resistance; (b) the electrical behavior of conductors and insulators; (c) the main components of an electrical circuit; (d) how to measure electric current, voltage, and resistance; (e) which factors affect the resistance of a conductor.

Students accessed AR-SaBEr's learning materials through the main menu of their tablets which contains three topics: (T1) electricity current; (T2) voltage, and (T3) resistance. Each topic consists of three activities and each activity includes four phases: (P1) the background information to understand the main concepts related to the activity; (P2) an AR-based simulation of the physical principle related to the activity; (P3) and (P4) general description of phases (P1) and (P2), respectively. The learning application promotes self-directed learning within an environment that allows free access to learning resources. In such an environment, students must decide which activities and phases to perform, in which order, and what learning resources they will use. While navigating through the application, students have the opportunity to discover the basic principles of electricity through reading and experimentation.

The AR-based simulations included in AR-SaBEr were aimed at taking advantage of AR affordances for science learning. The experimental activities were structured around students' manipulation of 3D shapes, which mimicked circuit elements. The use of these tangible objects was introduced to enhance the learning experience [4], [35], [36]. The simulations make the invisible visible to promote deeper understanding of electrical phenomena and process [4], [37]. Additionally, the application was designed to simplify the complexity of reality avoiding cognitive overloading. It presents activities to students that are neither too complicated nor too simple, and aimed at arousing curiosity and motivating them to explore the learning environment [4].

Regarding scaffolding strategies, AR-SaBEr includes both background knowledge and experimental support to assist students in their discovery process. The background knowledge support associated with each simulation activity comprises explanatory texts of the concepts and experiments related to the activity. Whereas the experimental support includes several mechanisms to assist learners in the discovery of the basic principles of electricity through simulations. Each simulation activity allows testing a hypothesis by varying one or at most two variables signaled by the application. The application provides tangible elements that act as electrical measuring tools such as voltmeter, ammeter and ohmmeter to test the variables of the system. The visualization support includes the superposition over the scene of the values gotten by the measuring tools. For example, fig. 2 shows the simulation activity designed to test the effect the thickness of a wire has on resistance (fig. 2a) within the topic T3. Fig. 2b shows the ohmmeter used to take the measures that the application superimposed upon the scene (fig. 2c). Fig. 2d shows a final test included to help learners to reflect upon the main conclusion of the activity.

4 METHOD

AR-SaBEr combines affordances of AR technology with scaffolding mechanisms in a learning environment that assists learners in discovering the basic principles of electricity. In a previous work [12], AR-SaBEr have proven effective to foster learners motivation. However, the tool might require learning scaffolding strategies to help focusing students' attention on the discovery activities rather than on the AR-technology and improve learning effectiveness. Consequently, researchers deployed two versions of the application with different learning scaffolding strategies. The two versions of AR-SaBEr had the same content, the same activities, provided learners with the freedom to choose activities, and included the knowledge based and experimental support described in the previous section. What differentiated them was the learning support provided to suggest learners the most relevant and productive tasks [13], [21]. The advice was given with visual clues that highlighted the suggested activities and this was based on the learner's knowledge of the fundamental concepts of electricity covered in this simulation environment. All learning activities were presented to the control group (CG); therefore, participants in this group chose the learning activities according to their willingness to work, with no extra help from the system. On the other hand, experimental group (EG) received visual clues that recommended learning activities according to their results in a knowledge pretest, and they used the AR-SaBEr_E simulator. This supporting mechanism was called knowledge-based scaffolding by Fund [38]. For both groups, once the learner performed an activity, the activity ceased to be recommended. Therefore, an experimental-control group design was used to compare two ways of recommending learning activities on participants' acquisition of electricity basic concepts. The independent variable of the study was the scaffolding learning support designed to guide learners to choose the learning activities.

In order to gain insight into the behavioral patterns of learners that might occur during the discovery learning process, learners' interactions with the tool were explored.

In this study, the specific research questions aimed at exploring whether the scafolding service have any impact on students behavior (RQ1, RQ2, RQ3) and on students learning outcomes (RQ4) were the following:

RQ1: Are there any differences in students' behavioral pattern depending on the scaffolding strategy used?

RQ2: Is there any difference in students' overall simulation time spent during the experience depending on which scaffolding strategy they used?

RQ3: Is there any difference in students' overall reading time spent during the experience depending on which scaffolding strategy they used?

RQ4: Are there any differences in students' learning effectiveness depending on which scaffolding strategy is used?

4.1 Participants

In this study ninth-grade students participated from three schools located in the south of Madrid. Students' participation in the learning activity was mandatory. The sample consisted of 82 students (age 14–17, *M*=14.5 *SD*=0.7). Ten students did not complete some of the tests and thus were not considered for the purposes of this study. Students were randomly assigned to either of two groups: the control group (CG) included 18 males and 22 females whose ages ranged from 14 to 15 years old (*M*=14.2, *SD*=0.4), and the experimental group (EG) included 18 males and 14 females from 14 to 17 years old (*M*=14.75, *SD*=0.91).

Students had basic computer skills (e.g. elemental computer operation, the ability to use a web browser), which form part of their computer science curriculum. However, they had not previously used any AR application before.

4.2 Procedure

First, in each of the selected schools, students received traditional instruction related to the concepts involved in the activity by their respective teachers who followed the same physics curriculum. In the subsequent week, students were randomly assigned either to any of the groups (CG or EG). Each student received a tablet with the AR-based application installed and the set of physical objects required for the intervention. Prior to their actual interaction with the application on an individual basis, the students received brief oral instructions on its use by the researchers. Students started by completing a knowledge pretest. Then, they started the interventions in presence of their teachers and the researchers. The interventions lasted 50 minutes. Throughout this time, students received technical and procedural help from the researchers and their teachers respectively. After the completion of the interventions, students completed a knowledge posttest questionnaire. All the surveys and tests were embedded in the application.

The activity lasted 100 minutes. The maximum amount of time given for the completion of the pretest and posttest questionnaires was 20 minutes for each of them. All students completed the test within the stipulated time. Students who completed the test before the stipulated time waited for their peers.

4.3 Measurement Instruments

To assess the effectiveness of the interventions on learners' electricity basic concepts, knowledge pretest and posttests were conducted and analyzed. The pretest and posttest were comprised of 10 multiple-choice questions, each worth one point. Tests were designed by researchers and examined as to content validity by teachers of the high schools taking part in the study. Two example questions from pretest and postest, respectively, are listed as follows:

Pretest sample question:

> "Q4. What instrument measures electrical current? (a) The voltmeter, (b) The ammeter, (c) The ohmmeter, (d) None of the above."

Posttest sample question:

> "Q4. What is electric current measured in? (a) Amperes, (b) Coulombs, (c) Volts, (d) None of the above."

Web usage mining was applied in order to understand how learners engaged in the activities provided by the AR-based application [39]. Learners' click-stream of page views and time spent in each page were captured in the form of log files. The logs recorded learners' interactions

TABLE 1
ADJUSTED RESIDUALS TABLE FOR CONTROL GROUP

	Start	RSC_I	RHSC_I	RHEC_I	E_I	RSC_V	RHSC_V	RHEC_V	E_V	RSC_R	RHSC_R	RHEC_R	E_R	End
Start			3.76		2.76	1.96								
RSC_I				2.31	2.14									
RHSC_I		3.08	7.77	6.78										
RHEC_I					5.04									
E_I					9.20			2.07						
RSC_V								2.59	4.68					
RHSC_V								3.18						
RHEC_V									6.06					
E_V									7.96					
RSC_R														
RHSC_R												4.24		
RHEC_R													4.35	
E_R											2.37		10.10	9.17
End														

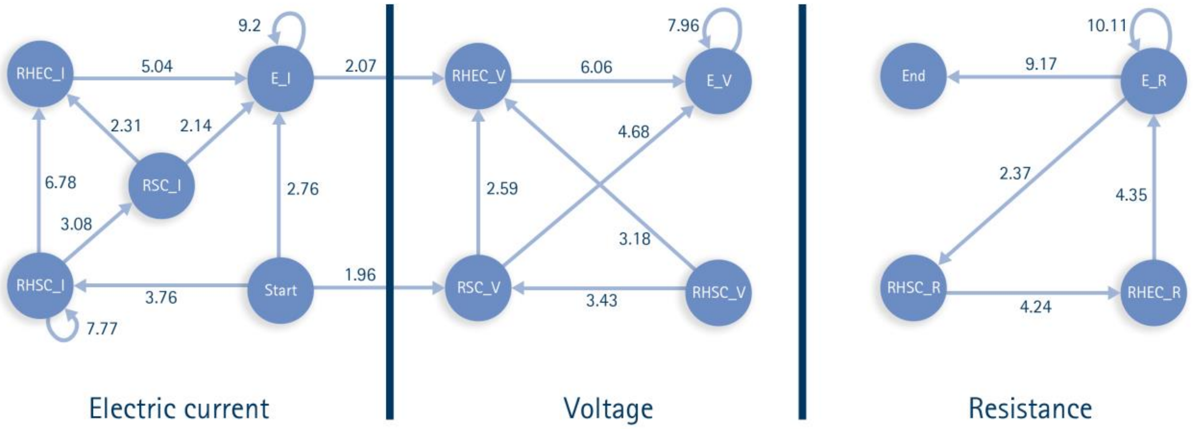

Fig. 3. Behavior transition diagram for control group (RSC_topic: reading subject content; RHSC_topic: reading highlights of subject content; RHEC_topic: RHEC_topic: reading highlights of experiment content; E_topic: experiment; Start, End).

with the application in the order of their occurrence. In this study, the coding scheme reflected the structure of the application with a total of 14 codes, one for each page:

RSC_t: It includes subject content. The learners have access to the background information on the topic "t" ("t" can be "I", "V", or "R" for electricity current, voltage or resistance, respectively). It corresponds to phase P1. For example, for the topic T3 a text of 145 words is presented to participants. The text defines what is the electrical resistance of a material.

E_t: It includes an experiment. It corresponds to phase P2. The learners have access to the experiments associated with the topic "t". Fig. 2b and fig. 2c show two screenshots of the experiment of topic T3.

RHSC_t: It includes highlights of subject content. The learners have access to the text that describes what are they going to learn by reading the subject content of the topic "t". It corresponds to phase P3. For example, the text RHSC_I is: "In this section you will learn (1) What are the elements of a circuit?; (2) What good are the circuit elements?, and(3) How to represent graphically a circuit?."

RHEC_t: It includes highlights of experiment content. The learners have access to the description of the experiments on the topic "t". It corresponds to phase P4. For example, for the topic T1 the text that highlight the experiment content is: "In this section you will learn (1) How to build simple electrical circuits using a battery, a lamp, a fan and a switch and, (2) you will observe the electrical circuit working."

Start: The page where the activity begins.

End: The page where the activity finishes.

RSC_t, RHSC_t and RHEC_t correspond to reading tasks, E_t correspond to experimental tasks and Start and End correspond to the first and last empty tasks included for completeness.

5 RESULTS AND DATA ANALYSIS

5.1 Behavioral Sequential Analysis

This part of the study was aimed at exploring the research question RQ1. Lag sequential analysis (Bakerman, & Gottman, 1997) was used to identify and visualize the learners' behavioral patterns when using different scaffolding services. The analysis used the logs recorded with the click-stream of page views for the learners. The adjusted residual tables of the students' behavioral transitions were determined for the control group (n = 40) and the experimental group (n = 32), as shown in Tables 1 and 2 respectively. The rows represent the starting behaviors, and the columns represent subsequent behaviors. A Z-value greater than 1.96 means that a behavior-sequence reaches the level of significance (p<.05). Based on the significance sequences from Tables 1 and 2, diagrams of behavioral transition were prepared (fig. 3 and 4, respectively); the arrows indicate the direction of a significant sequence, and the number refers to the Z-value. It should be noted that only those Z-values of significant sequences are shown in fig. 3 and 4.

Fig. 3 shows the significant behavioral sequences in the control group divided into nine, six, and five behavioral sequences related to the topics electricity current, voltage, and resistance, respectively. Furthermore, the sequences (Start → RSC_V and E_I → RHEC_V) show the transitions between the electricity current and voltage topics.

From the inspection of significant behavioral sequences related to the electricity current topic, the sequence Start → E_I suggests that the students were mainly interested in doing the simulations. Two other sequences (E_I → E_I, E_I → RHEC_V) contribute to stress the previous statement. Indeed, the circular pattern E_I → E_I shows students' interest in doing the simulations, whereas E_I → RHEC_V shows that when they finalized the simulation activities, they continued working on the voltage topic. It is worth noting that for the control group the preference for experimentation over reading is a behavioral pattern

TABLE 2
ADJUSTED RESIDUALS TABLE FOR EXPERIMENTAL GROUP

	Start	**RSC_I**	**RHSC_I**	**RHEC_I**	**E_I**	**RSC_V**	**RHSC_V**	**RHEC_V**	**E_V**	**RSC_R**	**RHSC_R**	**RHEC_R**	**E_R**	**End**
Start		2.88	9.18	2.88										
RSC_I					11.25									
RHSC_I		7.59	6.6											
RHEC_I		7.74		3.67										
E_I					9.4		3.39	3.16						
RSC_V									11.97					
RHSC_V						12.4			3.17					
RHEC_V						2.36		4.31	3.97					
E_V							2.11		6.34					
RSC_R													7.1	
RHSC_R										5.73	9.59			
RHEC_R													3.12	
E_R												2.3	12.1	6.29
End														

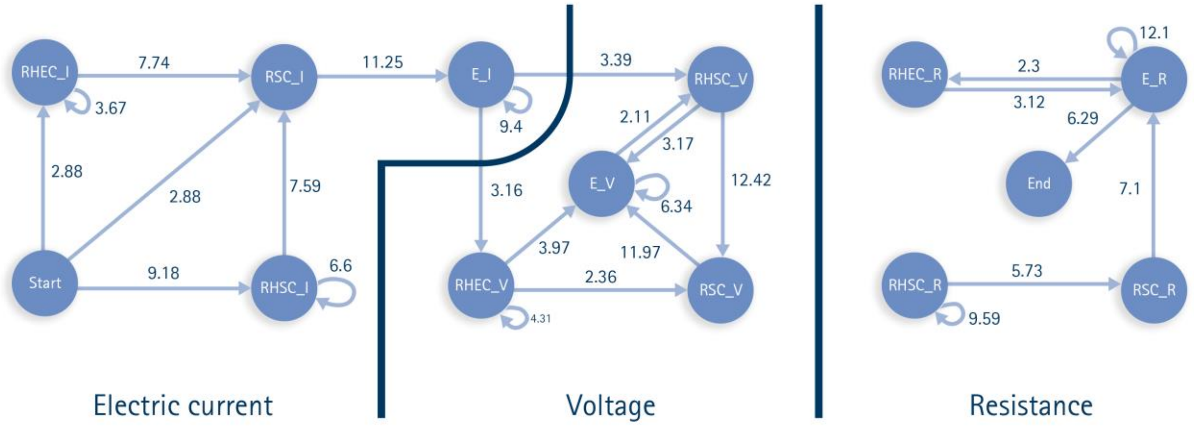

Fig. 4. Behavior transition diagram for experimental group (RSC_topic: reading subject content; RHSC_topic: reading highlights of subject content; RHEC_topic: RHEC_topic: reading highlights of experiment content; E_topic: experiment; Start, End).

that appears also in the other topics (E_V → E_V and E_R → E_R).

However, in the control group there were also students who read before experimenting. Indeed, there were similar reading behaviors in the electricity current and voltage topics (fig. 3). In both cases, the behavioral sequences show students' interest in reading about the subject before experimenting (RSC_I → E_I, RSC_V → E_V) or at least reading about the experimentation step before performing it (RHEC_I → E_I, RHEC_V → E_V). However, it is worth noting that the frequency of the first patterns (2.14, 4.68) is lower than the frequency of the last patterns (5.04, 6.06). Finally, RHSC_I → RSC_I and RHSC_V → RSC_V patterns suggest a planning learning behavior, whereas RHSC_I and RHSC_V represent browsing actions that show very limited interest in the topics.

The most remarkable fact regarding the behavioral patterns emerged in the resistance topic, namely, the absence of RSC_R (reading subject content) in any sequence. This suggests students' lack of interest in reading about this topic. The results indicate that students were only interested in browsing activities and doing simulations (RHSC_R → RHEC_R, RHEC_R → E_R, E_R → E_R). However, students cycled between these three sequences, which suggests they were seeking further information to execute the simulations successfully.

Fig. 4 shows the significant behavioral sequences in the experimental group. In the electricity current topic, the group read before experimenting (RSC_I → E_I), repeating experimentation (E_I → E_I), browsing information before reading (RHEC_I → RSC_I, RHSC_I → RSC_I) or reading or browsing as initial starting learning activities in the topic (Start → RHEC_I, Start → RSC_I, Start → RHSC_I). These results suggest that learners showed interest on instruct themselves about the electricity current topic or at least about the experiments before doing the simulations. The activities that comprise the voltage topic were almost equivalent to their counterpart in the electricity current topic; only the behavioral sequence (E_I → RSC_V) did not achieve significance. Finally, in the behavioral sequences RHSC_R → RSC_R and RSC_R → E_R indicate that students were interested in browsing information before reading and in reading before experimenting; students' interest by the simulation was also significant (E_R ↔ E_R) and the circular pattern E_R ↔ RHEC_R suggests that they were seeking information to execute the simulations successfully.

5.2 Analysis of Learners' Time Spent on Activities

This part of the study was aimed at exploring two specific research questions RQ2 and RQ3.

A Shapiro–Wilk test of normality distribution was used to examine the distribution of the simulation and reading time spent depending on which strategy was used. Since distributions were not normal, Mann-Whithney U tests were used to compare both strategies. For non-parametric effect size analysis, Cliff's Delta statistic was used [40]. The absolute value of the Cliff´s Delta can be considered small around 0.147, medium around 0.33, and large around 0.474 [41].

For the time spent doing simulations, result showed that there was no statistically significant difference between the two groups (U=504, Z=-1.5412, p=.124). There, we fail to reject the null hypothesis that there is no difference between groups. Instead for the reading time, result showed that there was a statistically significant difference between the control group (Mdn=22) and the experimental group (Mdn=231), U=111.5, Z=-6.000, p<.001. Cliff's Delta effect size value (δ=-.83) suggested a high practical significance.

The intervention included three different kinds of lectures that were coded as RSC_t, RHSC_t and RHEC_t referring to the reading of (1) subject content, (2) highlights of subject content and, (3) highlights of experiment content respectively. Mann-Whithney U tests were used to compare both strategies since data was not normally distributed. For the first code, result showed that there was a statistically significant difference between the control group (Mdn=16.5) and the experimental group (Mdn=225.5), U=107.5, Z=-6.0526, p<.001. Cliff's Delta effect size value (δ= -.83) suggested a high practical significance. For the second code, result showed that there was a statistically significant difference between the control group (Mdn=0) and the experimental group (Mdn=5), U=336, Z=-3.7572, p<.001. Cliff's Delta effect size value (δ= -.48) suggested a high practical significance. Finally, for the third code result showed that there was not statistically significant difference between groups (U=581.5, Z=-.7907, p=.433, δ=-.092). In this case, Cliff's Delta effect size value (δ=-.092) suggested a very low practical significance. Therefore, the difference on reading times was mainly due to the reading on subject content.

5.3 Learning Effectiveness Analysis

This part of the study explores the research question RQ4. An analysis of covariance (ANCOVA) was carried out to compare learning effectiveness depending on the strategy used. To investigate potential initial differences between groups an analysis of the pretest scores was performed. Result showed that there was no statistically significant difference between control group (M=4.55, SD=2.01) and experimental group (M=5.21, SD=2.19), F(1,70)= 1.81, p=.183, which indicates that the groups had similar background knowledge about electricity basic concepts before starting the experiment.

Before conducting the analysis of covariance (ANCOVA) on posttest scores, preliminary verifications were performed to confirm that there was no violation of the assumptions of normality, linearity, homogeneity of variances, and homogeneity of regression slopes. The sample satisfied the requirements for analysis of covariance. The skewness and kurtosis was between -1.0 and 1.0 for pretest and posttest scores, thus the assumption of normality is satisfied. The univariate general linear model procedure was used to test the significance of an interaction term in the model, made up of the covariate (pretest scores) and the groups. The result indicated that the assumption of homogeneous regression slopes is satisfied (F(1,70) =3.3337, p=.07).

After adjusting the posttest scores in the pretest (covariate), the following results were obtained. A statistically significant main effect was found for type of intervention on the posttest scores, F(1,69)=7.70 , p<.001, in favor of the experimental group (M=6.31, SD=1.63) over the control group (M=4.92, SD=2.12). Partial eta squared values was obtained from the ANCOVA test in order to determine the effect size of scaffolding strategy on the posttests scores. The partial eta squared values of 0.01, 0.06, and 0.14 are considered as small, medium, and large effect sizes, respectively. Partial eta squared= 0.10 obtained suggested a nearly large practical effect of the difference between the two groups. This finding suggests that participants from the experimental group showed significant better learning achievements than those of the control group.

6 DISCUSSION AND CONCLUSIONS

In this study, we attempted to investigate the effects of structuring student work on learning outcomes and behavior patterns in an AR-based environment. To this end, we designed AR-SaBEr, an AR-based simulation tool for teaching basic principles of electricity to ninth-grade students. The study integrated a quantitative analysis of the time learners spent interacting with AR-SaBEr and a sequential behavior analysis to examine the patterns of use of background information and simulations of two versions of the tool which included background learning and experimental support and differed in the learning support provided.

6.1 Differences in Behavioral Patterns

According to sequential analysis, participants from both groups sustained experiment activities along with the three topics of the intervention (E_I → E_I; E_V → E_V, and E_R → E_R). Moreover, quantitative results showed that there were no statistically significant difference on time spent by the groups on the corresponding experimenting activities.

In the other hand, the groups showed different patterns of activity when include reading activities (RSC_t, RHSC_t and RHEC_t). The behavioral pattern of the control group showed a weaker interest in reading about subject content before experimenting than in browsing information before experimenting. Conversely, the experimental group showed a tendency to read about the topic before experimenting. This difference of behavior patterns between control and experimental group might be due either to the personalization of activities, or to the restricted amount of the suggested activities. The personalization of activities promotes what is considered a positive inquiry learning behavior [23], whereas a restricted amount of information decreases the cognitive load [42] and might benefit learning outcomes. Therefore, it seems advisable to adapt the activities to the learners according to their background knowledge. In both groups, learners were more likely to read small pieces of information that guided or inform them rather than the information intended to provide background knowledge support. Further studies are necessary to determine what is the amount of information to provide to guarantee an effective background learning support in AR-based learning environments.

A sustained interest in reading about the subject content was not present in any group. However, the study demonstrated that the participants of the experimental group spent more time reading the background information on the three topics of the learning activity than participants in the control group. This suggests that guiding students to focus on relevant activities helps them to find out relevant information for experimentation.

6.2 Differences in Learning Effectiveness

Regarding the learning effectiveness of the two scaffolding strategies analyzed, after conducting a statistical analysis on the pre- and posttests scores, it was found that the learners' knowledge related to basic principles of electricity was better when the AR-SaBEr_E simulator was used. This result along with the behavioral patterns observed would suggest that focusing learners' attention on the subject matters they do not master is effective for discovery learning in AR-based simulator environments.

This study was an initial step toward understanding learners' behavior in AR-based simulated environments. Future research includes understanding learners' behavior in these environments when using different scaffolding supports for discovery based learning. It would also be interesting to investigate which scaffolding mechanisms adapt better to AR-based simulated environments with different levels of inquiry (e.g. highly, medium, open structured).

Results of this study demonstrate that learners take advantage of text knowledge support even in learning environments with other more appealing activities when they are supported in focusing attention on personal challenging activities. Under these circumstances, they exhibit learning behaviors which lead them to improve their learning outcomes.

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