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MEASURING THE EFFECTS OF USABILITY ISSUES AFFECTING AN ENJOYABLE LEARNING EXPERIENCE – A PATH ANALYSIS APPROACH

Costin PRIBEANU[1]
National Institute for R&D in Informatics – ICI Bucharest, Romania

E-mail: pribeanu@ici.ro

Abstract

Educational applications based on augmented reality (AR) are integrating real objects into a computer environment thus creating a more engaging and enjoyable learning environment for students. The interaction with real objects in an AR setting may lead to usability problem that affect the extent to which the user learning experience is perceived as enjoyable. The objective of this paper is to measure and analyze the negative influence of usability issues on the perceived enjoyment of using a Chemistry AR-based application. In order to better understand and explain students' perceptions by measuring both direct and indirect effects a two-step approach was taken. During the first step a prediction model is developed based on multi-level multiple linear regression. In the second step the model is refined and estimated using path analysis. The results revealed four factors having a significant influence: quality of the see-through screen, ease of reading the information on the screen, ease of Chemical elements selection, and fatigue.

Keywords: *e-learning, augmented reality, perceived enjoyment, user experience, path analysis usability, ergonomics*

1. Introduction

Augmented reality (AR) technology has a great potential to support novel approaches to education [4], [12], [13], [21]. Students can touch and hold real objects, control the learning process, and build knowledge by themselves. Apart from their pedagogical value, AR-based applications are increasing the intrinsic motivation by creating engaging and enjoyable learning environments for students [3], [14], [18], [21]. Implementation of the AR concept in desktop settings may create perceptual problems [2], [10], [11] which may lead to specific usability problems in terms of ease of learning how to operate, ease of use, and fatigue [15]. In turn, these negative effects may affect the extent to which the user experience with an AR-based application is perceived as enjoyable.

This work reports on the negative influence of usability problems on the user learning experience with an Augmented Reality Teaching Platform (ARTP). The platform has been developed in the ARiSE European project having as main objectives to assess the pedagogical effectiveness of introducing the AR technology in primary and secondary schools and to increase students' motivation to learn [22]. Three research prototypes (applications) implementing three learning scenarios have been developed on the ARTP. The application analyzed in this study implemented a Chemistry learning scenario and was targeted at understanding the periodic table of Chemical elements, the structure of atoms / molecules, and the chemical reactions.

The objective of this work is to measure and analyze the negative influence of usability problems on the perceived enjoyment of learning with ARTP. In a previous paper [16] a multiple linear regression analysis was carried on to identify the main factors affecting the learning experience. The results revealed three predictors: accuracy of visual perception, Chemical elements selection, and fatigue. In this paper we extend the analysis in order to better explain students' perceptions by measuring and analyzing both the direct and the indirect effects. The approach is based on a method consisting in two steps: (1) multilevel multiple linear regression yielding a prediction model and (2) refinement and estimation of the prediction model using AMOS for Windows [1].

The rest of this paper is organized as follows. In section 2, previous and related work is discussed with a focus on usability evaluation and specific issues related to the ergonomics of ARTP. The method and experiment are presented in section 3. In the next section, the predictive model is presented and the estimation results are discussed. The paper ends with conclusion in section 5.

2. Related work

2.1. Perceptual issues and usability problems in AR environments

Designing AR applications for usability is not easy since each real object requires careful implementation of specific interaction techniques. As Dunser & Billighurst [6] pointed out AR is an emerging technological field so many technological issues have to be solved in order to create usable applications. They are advocating for a user centered-design approach of AR systems and for evaluating applications with actual users.

Gabbard & Swan [7] proposed a usability engineering approach that is based on user-cantered design, user-based studies, and iterative evaluation. They illustrated their approach with a case study of analyzing how users perceive text in an outdoor AR setting. The authors are advocating for small experimental designs that focus on main issues.

Kruijff et al. [11] classified and analyzed the perceptual issues on a range of AR platforms with a focus on the correct perception of augmentations. Each category of platforms has specific perceptual issues. Their study concludes that while perceptually correct augmentation remain a difficult problem that could only be accomplished through improved hardware and software, more work on evaluation is needed to better understand the specific issues on different platforms.

Bai & Blackwell [2] analyzed several usability issues in AR systems based on the papers published by ISMAR conferences (International Symposium of Mixed and Augmented Reality). Their study highlights four areas of interest for usability evaluation: performance, perception and cognition, collaboration, and user experience. Regarding the user experience, the study mentioned the accuracy of visual perception and the accuracy and quality of sound. Regarding the user experience, the main issues are related to discomfort, headaches and eye pains.

2.2. Previous work in ARTP evaluation

During the ARiSE project several usability evaluations have been carried on for the Biology and Chemistry applications. The data samples collected in 2007 and 2008 included usability reports (prioritized list of usability problems), measures of effectiveness and efficiency, and answers to questionnaire. The answers to questionnaire included both qualitative and qualitative data (answers to open questions). The qualitative data helped evaluators to better understand the usability issues and helped developers to fix most of them.

In a previous work [14], the motivational value of the Chemistry application was evaluated based on the analysis of answers to the questionnaire. Students found the Chemistry scenario interesting, captivating and enjoyable. However, the analysis of quantitative data revealed several items with a low mean value (i.e. bellow 3.50 on a scale from 1 to 5) which suggest some usability problems related to the accuracy of the visual perception.

Iordache & Pribeanu [9] reported on the formative evaluation of the Biology application implemented on ARTP. In order to increase confidence in results, a comparison between quantitative and qualitative data has been done. The results showed that most of the usability problems were related to selection, accuracy of visual perception, and comfort in use (eye pains).

In a recent work [15] the ergonomic quality of the Chemistry application was analyzed by using a model with causal indicators that are influencing the perceived ease of learning how to use, perceived ease of use, and comfort in use. The results showed that the most important indicators for the ergonomic quality are the ease of reading the information on the screen and the ease of selecting a chemical element.

3. Method and empirical study

3.1. Method

The method used in this study is based on Cohen's path analysis [5]. Cohen noticed that a multiple linear regression leads to a flat model that only takes into account predictors having a direct effect on the dependent variable. Therefore he used the multi-level multiple regression in order to develop causal models that could better explain the correlation between variables. In a previous work [17] this approach was used in order to refine the causal model and assess its quality. The method has two steps:

- Development of the causal model based on multi-level multiple linear regressions.
- Model estimation, model refinement, and analysis of direct and indirect effects.

Cohen's path analysis enables the development of causal models in which the predictors of a dependent variable become dependent variable on the next level. This multi-level model has an increased explanatory power than a regression model since it shows how some causal influences are mediated by endogenous variables [5]. There is one limitation of the development path: since the model is developed level by level is possible to miss relationships between variables that are not on consecutive levels.

The second step enables an easy specification of the model and an automate computation of the direct and indirect effects. Model estimation allows checking the significance of causal relationships. The examination of modification indices makes it possible to identify missing relationships so the model could be further improved. This is an

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important advantage that overcomes the limitation mentioned above. Also, the model estimation with AMOS for Windows [1] makes it possible to assess the quality of the model (model fit with the data).

3.2. Equipment and data sample

ARTP is a desktop AR platform that has been registered by Fraunhofer IAIS under the trade mark Spinnstube®. The experiment has been carried on using an ARTP with 4 independent modules organized around a table on which real objects are placed [20]. A remote controller Wii Nintendo has been used as interaction tool for selecting a menu item.

The learning scenario for Chemistry has an introduction and three lessons, each lesson having several exercises. More details about the pedagogical goals, lessons, and exercises could be found in [19]. The Chemistry scenario integrates two kinds of real object: a periodic table and a set of colored balls (4 colors) symbolizing atoms. Each workplace has its own periodic table. By placing a ball over a chemical element it becomes an atom of that element and could be further used to form molecules. Previously created molecules could be further used for simulating Chemical reactions.

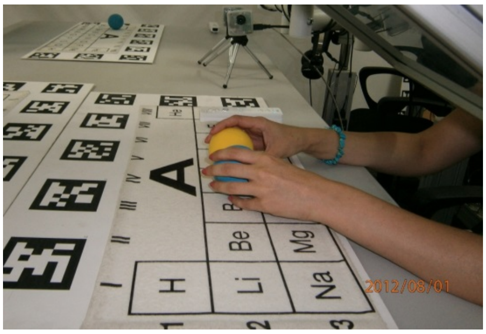

Figure 1. Student using the Chemistry learning application on the ARTP

The data was collected in 2012-2013. A total of 186 students (13-15 years old) from several schools in Bucharest tested the Chemistry scenario during a session of 30 minutes. None of them was familiar with the AR technology. After testing, the students were asked to answer a questionnaire by rating the items on a 5-point Likert scale. The data sample is gender balanced (96 boys and 90 girls). A data analysis has been carried on that revealed multivariate outliers (based on Mahalanobis distance, $p<.001$). Therefore two observations were eliminated which resulted in a working sample of 184 observations.

3.3. Variables

The variables used in this study, the mean value and standard deviation are presented in Table 1.

Table 1. Variables

No.	Item	M	SD
ERG1	Observing the real objects through the screen is clear	3.36	0.90
ERG2	Understanding the augmentation of a real object was easy	3.22	1.11
ERG3	Selecting a Chemical element is easy	3.28	1.35
ERG4	Selecting a menu item is easy	4.47	0.99
ERG5	Vocal explanations are clear an understandable	4.41	0.90
ERG6	Reading the information on the screen is easy	4.08	0.88
CONF1	I felt tired after using the system	1.99	1.32

CONF2	After using the system I experienced headaches	1.73	1.19
CONF3	After using the system I experienced eye pains	1.91	1.24
PE1	Using ARTP is an enjoyable learning experience	4.27	0.91

First 6 items refer to ergonomic and usability aspects of the ARTP. Next three items refer to the comfort in use and the last item is the dependent variable in this study. The relatively high mean value of PE1 shows that students perceived the interaction with ARTP as an enjoyable learning experience.

First three items have low mean values suggesting that some usability problems are related to the clarity of the see-through screen, accuracy of the augmentation, and ease of selecting of Chemical elements. Menu selection and accuracy of vocal explanations were highly rated by students. As regarding the comfort in use (high mean value means lack of comfort) the students mainly complained about fatigue, then about eye pains and less about headaches.

A correlation analysis has been carried on based on Pearson's correlation coefficients. The correlation table is presented in Table 2. All independent variables are significantly correlated with the dependent variable.

Table 2. Correlation table

	ERG1	ERG2	ERG3	ERG4	ERG5	ERG6	CONF1	CONF2	CONF3	PE1
ERG1	1									
ERG2	.45**	1								
ERG3	.36**	.38**	1							
ERG4	ns	.17*	.15*	1						
ERG5	.17*	.18*	ns	.42**	1					
ERG6	.36**	.25**	.28**	.27**	.35**	1				
CONF1	ns	ns	ns	ns	-.16*	-.21**	1			
CONF2	ns	ns	ns	-.17*	ns	-.22**	.62**	1		
CONF3	ns	ns	ns	-.18*	ns	-.16*	.60**	.59**	1	
PE1	.36**	.26**	.35**	.15*	.17*	.36**	-.27**	-.15*	-.17*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Significant correlation coefficients are ranging from -0.27 to 0.62. Items related to the visual perception (ERG1, ERG2, ERG6) are inter-correlated, with correlation coefficients varying from 0.26 to 0.45. Items related to the comfort in use are highly inter-correlated (0.59-0.62).

4. Analysis and results

4.1. Predictive model development

The target variable PE1 (enjoyable learning experience) has been used as starting dependent variable by regressing on it the rest of variables. In the next levels only causal relationships that make sense have been introduced. For example, ERG5 can only be a predictor and is independent from ERG1, ERG2, and ERG6. Overall, eight multiple linear regressions have been made. The summary of results is presented in Table 2. The regressions have been done by using SPSS for Windows. In all cases the multiple correlation coefficients were significant.

Table 2. Results of regression analysis

Dependent variable	Adjusted R^2	F	Sig.	D-W
PE1	0.253	16.507	0.000	1.994
CONF1	0.462	79.523	0.000	2.012
CONF2	0.359	52.309	0.000	1.903
CONF3	0.028	6.240	0.013	1.776
ERG3	0.195	15779	0.000	1.827
ERG6	0.211	25.425	0.000	2.077
ERG4	0.171	38.791	0.000	1.599
ERG2	0.199	46.584	0.000	1.868

The correlations between the independent variables are not too high. VIF values are well bellow 10 with the highest value of 1.541 so there is no collinearity within our data. The Durbin-Watson test value is ranging between 1.599 and 2.077 so we can conclude that the residuals are uncorrelated. Table 3 displays the standardized regression coefficients, t-values, and significance

Table 3. Regression analysis – coefficients

Dependent variable	Predictor	β	t	sig.
PE1	ERG1	.196	2.730	.007
	ERG3	.220	3.165	.002
	ERG6	.183	2.579	.011
	CONF1	-.213	-3.255	.001
CONF1	CONF2	.403	5.988	.000
	CONF3	.363	5.394	.000
CONF2	CONF3	.572	9.537	.000
	ERG6	-.125	-2.092	.038
CONF3	ERG4	-.182	-2.498	.013
ERG3	ERG2	.260	3.477	.001
	ERG1	.190	2.447	.015
	ERG6	.145	2.020	.045
ERG6	ERG1	.311	4.672	.000
	ERG5	.300	4.506	.000
ERG4	ERG5	.419	6.228	.000
ERG2	ERG1	.151	6.825	.000

The results of the first regression show that only four independent variables have a direct effect on the dependent variable. Three of them are positively related to the visual perception of the real object, the Chemical element selection, and the ease of reading the information on the screen. The last predictor has a negative influence showing that the more tired the student feels the less enjoyable is the learning experience.

4.2. Causal model estimation

The causal model developed by multilevel multiple linear regression was specified and estimated in AMOS for Windows [1]. This step enables to analyze the interaction between factors and to explain the contribution of each factor. In Figure 2 the causal model is presented with standardized regression coefficients and explained variance for each endogenous variable. The model includes the error term for the variables that are not inter-correlated.

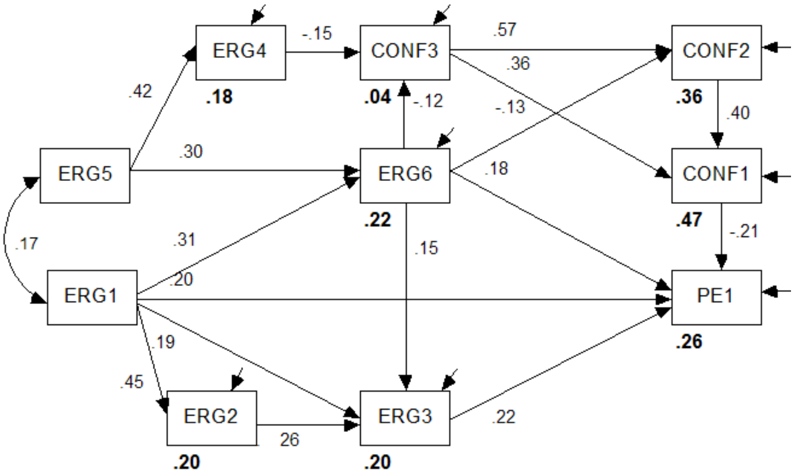

Figure 2. Initial causal model - estimation results

The indices of the model fit with the data are good, over the cut-off values recommended by de Hair et al. [8]: χ^2=24.739, DF=27, p=.589, χ^2/DF=.916, CFI=1.000, TLI=1.009, GFI =0.974, RMSEA =0.000, SRMR=0.0506.

The analysis of estimated regression coefficients shows that all causal relationships are significant (p< 0.05) except for ERG6 > CONF3. The model could be simplified by specifying ERG2 and ERG4 as exogenous variables. The refined model is presented in Figure 3.

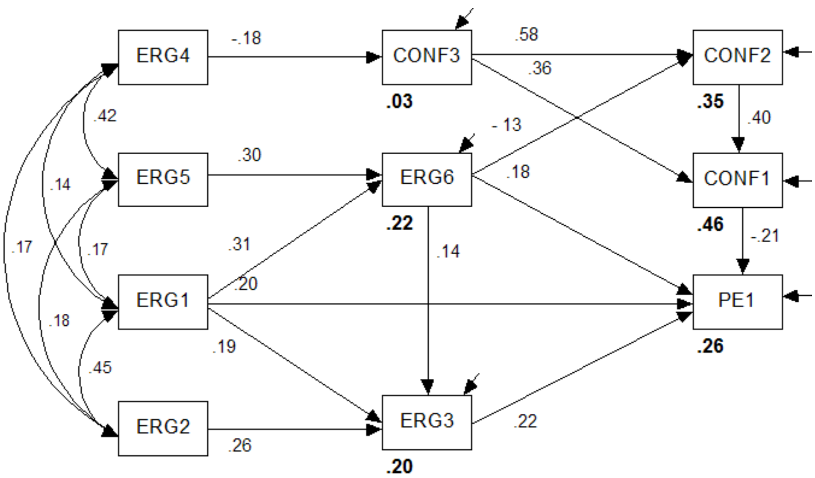

Figure 3. Refined causal model - estimation results

All causal relationships are significant at p<0.05 level. The indices of the model fit with the data are very good (slightly better than those of the initial model), over the cut-off values: χ^2=22.784, DF=25, p=.590, χ^2/DF=.911, CFI=1.000, TLI=1.010 GFI =0.977, RMSEA =0.000, SRMR=0.0492. The results show the benefits of the second step of the method: the refined model is simpler, the fit indices are better, and a non-significant causal relationship has been removed.

The estimation in AMOS enables the automate computing of direct, indirect, and total effects. In Table 4 the standardized total effects are presented. Results show that all 9 indicators are useful to explain the effects of usability issues on the perceived learning experience.

Table 4. Standardized total effects

	ERG1	ERG2	ERG3	ERG5	ERG4	ERG6	CONF3	CONF2	CONF1
ERG6	0.311	0	0	0.300	0	0	0	0	0
ERG3	0.235	0.261	0	0.044	0	0.145	0	0	0
CONF3	0	0	0	0	-0.182	0	0	0	0
CONF2	-0.039	0	0	-0.038	-0.105	-0.127	0.577	0	0
CONF1	-0.016	0	0	-0.015	-0.109	-0.051	0.596	0.401	0
PE1	0.310	0.058	0.221	0.068	0.023	0.228	-0.127	-0.086	-0.214

As regarding the direct effects, the most important predictors are ERG3 and CONF 1. The selection of Chemical elements was sometimes difficult, as shown by the results of a previous empirical study [14]. Also, the relatively low mean value of 3.28 (SD=1.36) shows that students found it difficult to select Chemical elements. The fact that the items ERG1 and ERG2 have also low mean values suggests that students experienced usability problems with the visual perception onto ARTP. Both variables are predictors of ERG3 thus indirectly influencing the dependent variable PE1.

A second factor affecting the learning experience is fatigue. The students felt tired after using the system. Some of them also complained about headaches and eye pains. The influence of selection techniques onto the user experience is not surprising since these are closely related to the real objects integrated by the application. The fourth factor is the ease of reading the information displayed on the see-through screen.

Besides the direct effect, reading the information on the screen (ERG6) is also an important mediator of indirect effects of ERG1 and ERG5 on the enjoyable learning experience. The indirect effects of ERG1 are also mediated by ERG3. If we take into account both direct and indirect effect of ERG1 it seems that the clarity of the see-through screen is a very important predictor. This finding shows the usefulness of the path analysis in explaining the users' perceptions. Overall, the results show that all 9 indicators are useful to explain the effects of usability issues on the perceived learning experience.

5. Conclusions

The enjoyable learning experience is influenced by two categories of factors. First category includes specific AR features that proved to enhance the user experience in e-learning [4], [9], and [17]. The second category includes ergonomic aspects of the AR platform and usability of the interaction techniques that are undermining the user experience.

In this work we measured the extent to which the specific ergonomic and usability issues are affecting an enjoyable user experience with an AR-based learning application. In order to measure both direct and indirect effects a method that is based on path analysis has been carried on. The results revealed four factors having a direct influence: the quality of the see-through screen (hardware issue), the ease of reading the information on the screen (software issue), the ease of Chemical elements selection (interaction technique), and fatigue after using ARTP (ergonomic issue).

These findings have several implications for developers. First, the visual perception in AR settings is a critical issue that may affect task effectiveness, visual fatigue, and perceived enjoyment. Second, the vocal explanations for user guidance are a useful feature that reduces the amount of information displayed on the see-through screen. Third, the selection techniques that are closely related to the real objects are specific to each AR application and should be carefully designed.

The results of this study show that all factors together account for 26% of the variance in the perceived enjoyable learning experience. This value is pretty high for a negative influence and suggests that developers should pay more attention to ergonomics and usability aspects that may undermine their effort to create enjoyable applications.

The method used in this study integrates and extends Cohen's path analysis. Causal models provide more insights in understanding the user perceptions than a multiple linear regression can do. Summing up the advantages, this two-step method enables: (1) estimating both direct and indirect effects, (2) revealing the variables acting as mediators, (3) analyzing the interaction between factors, and (4) refining and assessing the quality of the causal model.

Acknowledgment

This work was supported by the research project TEHSIN 203/2013. The AR platform and the Chemistry application were developed in the European project ARiSE (FP6 027039).

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[1] Costin Pribeanu is Senior Researcher I at ICI – Bucharest. His researches are focused on user interfaces, model-based design, usability and user experience evaluation, accessibility, and AR-based educational systems.