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Augmented Reality and Education in Electronics: Relationship between Usability, Academic Performance, and Emotions Experienced in Learning

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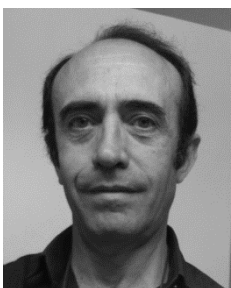
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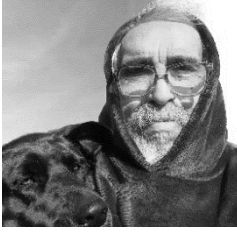
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AUGMENTED REALITY AND EDUCATION IN ELECTRONICS: RELATIONSHIP BETWEEN USABILITY, ACADEMIC PERFORMANCE, AND EMOTIONS EXPERIENCED IN LEARNING

ABSTRACT

Students often find difficult to understand the concepts and working details of electricity because its mechanisms of operation are invisible. The visualization of electricity through an AR app could assist students in understanding these concepts more intuitively and in improving their academic achievement. Due to the lack of studies on AR apps for electricity education, this study aimed to investigate the effects of an interactive AR app designed for teaching electrical circuits on students. The study investigates its impact on students' academic performance, explore its influence on their emotions, and examine the relationship between the perceived usability of the app and the student's learning outcomes and emotional experiences. The study was conducted in an electromagnetism laboratory with the participation of twenty-eight engineering students. The findings revealed that the students who used the augmented reality application presented better academic performance than those who participated in the traditional laboratory. Except for the students in the experimental group feeling less shame, there were no discernible variations between the students' feelings in the two groups. Anxiety increases in both groups. The AR application proved to have usability rated as good, but it was not evident that it correlated with academic performance, or the emotions students experienced. Only one relationship was determined between the perceived consistency of the system and hopelessness.

KEYWORDS

Augmented reality, engineering education, emotions, learning technologies, usability.

I. INTRODUCTION

Augmented Reality (AR) technology integrates real and virtual objects in real-time, the latter usually in 3D format [1]. Augmented reality applications are generally used with mobile devices, such as smartphones and tablets, mainly using targets as the means to determine the position of virtual objects[2]. This technology has expanded in the last decade in different areas [3], including educational processes and business training [4].

In education, it has been incorporated into several subjects [5] because it contributes to an engaging learning environment for students [6]. In STEM (Science, Technology, Engineering, Mathematics), it has been concluded that AR applications have characteristics aimed at acquiring the necessary competencies of the disciplines and provide a metacognitive scaffolding and experimental support for inquiry-based learning activities [7].

In particular, AR is considered a promising technology for engineering education. Engineering deals with the design and construction of artificial artifacts. Understanding these artifacts is difficult, as they can have complex 3D structures with non-visible properties. AR has the potential to help learn the structure and behavior of such artifacts [8].

On the other hand, incorporating AR technology into engineering education can also favor the abilities of future engineers to join Industry 4.0. This industry is characterized by increasingly digitized and optimized operations integrated into networks under Industrial Augmented Reality (IAR) [9].

IAR is one of the critical technologies targeted by the Industry 4.0 paradigm to improve industrial processes and maximize worker efficiency [10]. This technology has been mainly applied in assembly, maintenance, operations, supervision, simulation, and training in the automotive, mechanical, electronics, and aerospace industries [11,12]. Therefore, incorporating this technology in engineering education could not only affect academic performance in the short term but could also provide engineering students with long-term skills to enter the job market of an increasingly digitized industry.

In engineering education, one of the areas where AR has been used is electronics [13]. Students often have difficulty understanding the concepts of electricity because it and its mechanisms of operation are invisible [14], considering this complex matter[15]. The visualization of electricity through an AR app could assist students in understanding these concepts more intuitively and in improving their academic achievement [16].

On the other hand, emotions are a fundamental factor in education. [17]. In engineering education, emotions play an essential role, but research on the subject is scarce [18], and their relationship with learning processes needs to be sufficiently studied [19].

Different factors can affect emotions, such as the instruments and technologies students use, with usability being a key issue. Usability is a quality attribute that evaluates the use of user interfaces. Thus, usability must also be taken into account[20]. Poor usability limits the potential benefit of educational resources since students could experience, at the same time, difficulties with the technological interface, along with the challenges of learning the contents presented [21] But even though usability plays an important role[22], with exceptions[23],

this aspect has not always been considered despite playing a crucial role in the effectiveness of educational technologies.

Although AR technology has been successfully adopted in different areas of engineering education, including electronics training, there are no studies linking academic performance, usability, and emotions in the teaching-learning process (see Table 1 for a summary of variables analyzed, according to a systematic review) [24]. Considering the significance of emotions in the learning process and the usability of apps, it is crucial to explore students' emotions using augmented reality apps, the impact of the usability, and their subsequent effects on academic performance. Therefore, this analysis could better guide how institutions incorporate this technology in the classroom.

For this reason, the present research aims at establishing the relationship between academic performance with usability and emotions experienced when learning by using an augmented reality application on electronics. In particular, it aims to answer the following questions:

- a) Does using the AR app influence students' academic performance?
- b) Does the use of the AR app influence emotions?
- c) Is the perception of usability related to learning outcomes and emotions?

To answer these questions, an experience has been conducted with two groups of students who used equivalent electrotechnical laboratories. One group used an augmented reality application, while the other used physical instruments, both remotely, due to the confinement due to the COVID-19 pandemic.

The article's structure is as follows: in section II, the theoretical framework is developed, and the hypotheses are presented. The methods used are discussed in section III. Then, the results and the discussion are presented in sections IV and V, respectively. Finally, the conclusions and limitations are presented in section VI.

II. THEORETICAL BACKGROUND AND HYPOTHESES

A. AR app and academic performance

According to a recent systematic review on the topic, seventeen studies have been conducted to analyze the impact of AR apps in engineering education [24]. These studies have covered the acquisition of knowledge, as well as spatial, laboratory, or assembly skills. Of these, 15 have shown a positive impact. In the field of teaching electronics, only two studies were found. In the first one, students, with the support of a smartphone, via videos, graphics, and links to access complementary material to the electrical circuit exercises, performed better academically than those who attended a laboratory with conventional materials [25]. In the second experience, laboratory students had to design a sequential control system for filling a tank with three types of liquids using a development board. In this case, there was no significant difference in the academic performance of the group that used AR compared to the control group [26]. In both studies, the applications hardly supported any interactivity.

Therefore, we consider it necessary to evaluate the impact of interactive apps on academic performance. Therefore, we formulate the following hypothesis:

H1: The interactive AR app improves academic performance in students.

B. Emotions

Students' effective management of emotions reduces learning time and thus improves their performance [27]. Positive emotions promote knowledge construction and develop students' problem-solving abilities [28]. This can be evidenced in obtaining better results on evaluating comprehension capacity, transfer, and application of knowledge [29]. However, negative emotions can also promote greater attention in the learning environment, generating more excellent cognitive activity and information processing in greater detail and better learning outcomes [30].

In the academic context, emotions can be classified according to the dimensions of the Pekrun's model [31]. This model classifies emotions into three dimensions: object focus (related to the success and result of activities), valence (pleasant or unpleasant), and activation (agitation or stimulus) [32]. Regarding the valence dimension, emotions are classified into positive (pleasant sensation) or negative (unpleasant or uncomfortable sensation). Concerning the activation dimension, emotions are classified into activation emotions (producing a high degree of agitation, such as fear, anxiety, anger, etc.) and deactivation emotions (producing a low degree of agitation, such as depression, calm, boredom, etc.).

On the other hand, there is a relationship between motivation and emotions [33]. Previously, students' motivation when using AR apps in engineering has been studied [34,35]. The use of this technology increases the interest and motivation on the part of the student and promotes active participation in the learning process [34], which coincides with the results in other areas of learning [35].

Therefore, we may claim that AR technology in engineering education can also positively influence emotions during their learning by improving students' motivation. However, the authors have not found studies on emotions related to the use of AR in engineering education [24]. Therefore, we formulate the following hypothesis:

H2: The interactive AR app positively influences emotions.

C. Usability

One of the fundamental aspects of usability is assessing the degree to which a person believes a specific technology can be used effortlessly [36]. Since it enables the best use of all the features offered by the system, academics have been interested in evaluating the usability of educational systems [37]. However, usability problems may prevail in mobile applications used in education, which can negatively impact student learning. For this reason, software developers have incorporated usability evaluations into their application development process [38].

As for AR applications, these allow a new type of educational interactivity for the participants. However, some user experiences and usability problems must be solved to accept this technology in education [39]. And while many studies have indicated that the use of AR in education is more beneficial than traditional methods, the usability of AR is crucial to achieving the desired user experience, especially in three main metrics: efficiency, learning ability, and user satisfaction [40].

Usability has also been measured in AR apps used in the learning process in engineering [15]. However, none has analyzed its relationship with other factors. Therefore, we formulate the following hypothesis:

H3: The perception of usability of the interactive AR app is related to learning outcomes and emotions.

III. EVALUATION

A. Educational objective and context

This experience aims to validate the hypotheses established in the previous section. The research was carried out in June 2021. Twenty-eight students out of 40 of the electromagnetism course in the mechanical, industrial, mining, civil, and environmental engineering careers participated in the study. Despite the small size of the sample, the results of the study are informative because of the lack of studies on the concerns addressed. Furthermore, the heterogeneity of the participants is representative of different engineering studies and profiles. Finally, it provided us with a chance to gather first-hand information to determine potential usability problems that had yet to be detected during the development of the application. Small samples have previously been used to measure various aspects of AR apps [41,42].

A quasi-experimental study was carried out with two groups. The first (experimental group) used an AR application and the second (control group) traditionally performed the laboratory. Pre-test and post-test were applied to both groups. Eighteen students belonged to the experimental group and ten to the control group. The groups were not formed randomly but opportunistically, taking advantage of the two laboratory sections formed in the course (Figure 1).

B. Process

Due to the COVID-19 pandemic restrictions, both labs were conducted using the Zoom video conferencing software.

The experimental group of students participated in the laboratory, where theoretical concepts of electrical circuits were explained, and practical exercises were carried out with example videos using the AR application. After that, the students had thirty minutes to use the AR application. The control group, in the videoconference, was guided with explanations of the educational use the physical instruments to teach electrical circuits. The students could solve doubts to the extent of the course of the laboratory. Both groups participated in two laboratory

sessions of three hours, each distributed over two weeks. The tests were applied at the beginning of the first laboratory and the end of the second laboratory.

C. Resources Used.

For the experimental group, an AR application called "INGAR DC Analysis" was used (Figure 2), which analyzes the direct current (DC) in resistive circuits composed of batteries, resistors, and light bulbs [43].

To help the student understand how these components behave in an electronic circuit, this application enables the user to set, under carefully monitored safety conditions, the voltage values of batteries, the resistance values of light bulbs, and the resistance values of resistors. Using a smartphone or a tablet, and a QR code, students can choose between five circuits, in series or parallel. Then, using other QR codes (see Figure 2), they can incorporate batteries, resistors, and ampoules into the circuit. When one of these elements contacts one of the circuit branches, the application calculates the voltage and amperage values that pass through each element incorporated in the circuit. Additionally, the colors of circuit branches vary according to how strongly current flows through them. Branches are slightly golden at low current densities (Figure 3.a), and emit a bright red light with strong current intensities (Figure 3.b). This application has a high degree of interactivity (level IV: real-time interaction, according to Aqel [44]), because the student can interact in a simulation where stimuli generate complex responses.

In previous evaluations, it was verified that the application has high technological acceptance by students [40]. The factors influencing acceptance were perception of usefulness and of being pioneers in the use of new technologies. These elements are reinforced by both the social influence of the context and the extent to which a student thinks using technology is helpful for his daily life [45].

D. Measuring instruments

Because the user experience is conducted in an educational context, the authors decided to use the AEQ scale (Achievement Emotions Questionnaire) to measure emotions since it is a consistent and validated scale in that context [31]. The AEQ scale measures emotions by offering a series of statements about the emotional state, which the subject must assess to what extent the statement corresponds to their emotions and feelings using a Likert scale, ranging from very little (value 1) to extremely (value 5).

AEQ measures the following emotions: positive emotions with activation (enjoyment, hope, and pride), negative emotions with activation (anger, anxiety, and shame), and negative emotions with deactivation (despair and boredom). The scale can measure emotions at different stages of the learning process. This favors the ability to analyze the participants' emotional state while interacting with augmented reality technology. It can also be evaluated before and after using it. However, the measurement of emotions in these three learning moments entails a high number of items to be assessed by the student (80 items). Therefore, the authors decided to utilize AEQ twice to assess the subjects' emotional states: before beginning the learning activity (the student judges how he/she felt shortly before beginning

to use the tool) and following completion of the task (evaluates how he/she feels after having finished the experience). This meant evaluating a total of 30 items.

Usability was measured by means of the System Usability Scale (SUS), which is the most widely used standardized questionnaire to assess perceived usability [46]. The SUS scale is a 10-item questionnaire scored on a 5-point Likert scale (1: strongly disagree to 5: strongly agree). Its advantages include versatility, simplicity, low cost, accuracy, and validity [47].

Finally, a pre-test and a post-test of 5 questions were defined to measure knowledge. The tests consisted of two theory questions and three questions where the student had to solve an exercise, with each question providing four alternative choices with an equal score.

IV. RESULTS

Below are the results for learning outcomes, emotion, and usability. The *Shapiro-Wilk* test was applied to analyze distribution of samples since the data set are composed of fewer than 50 elements. The *Student's t*-test was used to test the differences between means for the data sets that presented a normal distribution. The *Wilcoxon* test was used for the data sets that did not present a normal distribution. The *Spearman* correlation coefficient was used for the analysis because the usability sample did not present a normal distribution.

A. Learning Outcomes

Table 2 shows the results of the level of knowledge obtained by the students, both in the control and experimental groups. The levels of understanding of both groups before starting the learning experience did not present significant differences (2.39 vs. 2.10). However, in the knowledge post-test, it can be seen that the experimental group obtained better results than the control group (4.17 vs. 2.40) and that this difference is significant (marked in bold in Table 2). Performing an analysis of the evolution of each of the groups, considering the pre-test and post-test, the control group did not have a significant difference (2.10 vs. 2.40, p -value=0.30). On the contrary, the experimental group presented a statistically significant improvement, concerning the initial knowledge level (2.39 vs. 4.17, p -value=0.00).

B. Analysis of Emotions

The student's emotions were measured in the control and experimental groups (before and after participating in the laboratory). The measurement of emotions showed no significant differences between the control and experimental groups, both at the beginning and end of the laboratory. Table 3 shows the evolution of emotions for each group. In the control group, a significant increase in anxiety was observed (2.70 vs. 3.45). On the other hand, in addition to presenting a significant increase in anxiety (2.85 vs. 3.56), the experimental group presented a significant decrease in shame (4.11 vs. 2.89).

C. Usability Study

The 18 students of the experimental group participated in the usability study. The degree of usability presented by the application obtained 76.81 points, rated as good [46].

Then the correlations between usability, academic performance, and emotions were determined. After the analysis, no global correlation of usability was found with neither the knowledge acquired nor the different emotions measured in the post-test. However, a particular correlation was found between hopelessness and the perception of inconsistency in the application's usability, item 6, "The tool presents quite a few inconsistencies" of the SUS scale (*correlation coefficient*=0.48; *p-value*=0.04).

V. DISCUSSION

This section summarizes and discusses the results obtained for each hypothesis, dedicating a section to each one.

A. The use of INGAR DC Analysis improves the learning of electrical circuits.

The results indicate that the students who participated in the laboratory using the AR app obtained better academic performance compared to the students who participated in the traditional laboratory. Therefore, the hypothesis is accepted "*H1: The interactive AR app improves academic performance in students*".

Previously, the impact of AR apps in the area of engineering education has been analyzed. This technology has proven effective when incorporated into instruction, This technology has proven its effectiveness when incorporated into instruction by using mainly 3D models. [24]. The results of this study complement other existing studies. In addition, it demonstrates that this technology is effective when used in another field of knowledge, such as electronics.

B. Students' emotions do not vary when participating in a laboratory with AR technology.

Concerning the emotions experienced, the results do not indicate significant differences between the experimental and control groups in positive and negative emotions in general. However, anxiety increased in both groups near the experiment's conclusion, as seen in prior augmented reality investigations [48]. Studies in other areas have also demonstrated that anxiety increases in students when they are evaluated [49]. In addition, students who used the AR application felt less embarrassed after the experiment. The above is consistent with results from other studies, which relate decreased embarrassment to students' increased sense of self-efficacy [50]. Thus, the decrease in the shame of the experimental group may be related to their better academic performance. And although there is no evidence for this claim, this aspect could constitute a future research line. However, as already mentioned, in this study, there was no evidence that the use of AR technology has increased the positive emotions of students, as in other previous studies on academic performance[51,52]. A possible explanation can be found in the fact that the groups had to work online due to the pandemic. In conclusion, the "*H2: The interactive AR app positively influences emotions*" is rejected due to no evidence was found.

C. There is no correlation between usability learning improvement and emotions experienced by students.

The analysis was carried out, and there was no evidence of a correlation between usability, academic performance, and emotions. Therefore, the "*H3: The perception of usability of the*

interactive AR app is related to learning outcomes and emotions” must be rejected. Performing an individual analysis between each of the items of the SUS instrument with academic performance and emotions, a significant, although moderate, correlation was found between student’s hopelessness and inconsistency of the tool. This shows that attention must be paid to the application design and functionality to avoid impairing the cognitive process of learning activities where these tools are used [53]. Although no similar studies with AR technology in education exist, our findings differ with results in other areas, where moderate correlations were found between emotions and usability [54,55].

D. Theoretical and practical implications

The results support previous studies by showing that incorporating AR applications into instruction can improve student academic performance. That provides additional validation of this technology's effectiveness in education, in particular in electronics. Also, the study demonstrates the importance of AR app design and functionality: The analysis revealed a moderate correlation between students' sense of hopelessness and the inconsistency of the AR tool used. The above highlights the importance of paying attention to the design and functionality of AR applications to avoid negatively affecting the cognitive process of learning activities. These findings underscore the need to consider usability when developing and implementing AR applications in educational settings.

The results of the study have some straightforward implications derived from the positive results obtained. In particular, educators and educational institutions can consider incorporating this technology as a tool to improve teaching and learning in engineering. In addition, consistency between the concepts introduced in the classroom and the conceptual model offered by the AR app is a crucial element in educational applications. Moreover, anxiety was observed in both groups. Educators need to be aware of the potential emotional effects of the technology used and consider strategies to promote positive emotions and reduce anxiety in students. A candidate explanation of anxiety increase on both groups is that students of both groups had to work online, in the context of the COVID-19 pandemic. If this was proved to be true, it would highlight the importance of addressing students' emotions during online teaching and providing an emotionally supportive environment. However, this hypothesis must be further assessed in future studies.

E. Validity

Regarding the design validity of this study, the experimental and control groups were made up of subjects enrolled differently, as they were studying the subject of electromagnetism in the third year of various engineering career. They all had the same level of knowledge going into the laboratory (Table 2), and there were no significant differences in the emotional states between the two groups (Table 3) before the experience. Therefore, the experimental and control groups are valid to compare them in the study.

F. Limitations

We can identify some threats or limitations of the study. First, the groups were not formed randomly and were trained according to the enrolled laboratory sections, so there is no certainty that the sample is representative. Secondly, the study sample was small, which may

also influence its representativeness. Thirdly, the experiment was carried out during confinement due to the COVID-19 pandemic. This might have impacted how the standard laboratory was run (through videoconference), how the experimental laboratory's students were supported while using the AR app, and how the students felt while being kept in confinement.

VI. CONCLUSION

We can conclude that incorporating AR technology in an electrotechnical laboratory significantly improves students' academic performance. As a consequence, AR can help in implementing educationally effective remote and decentralized laboratories for teaching electrical circuits, with the benefits that this can mean for students and academic institutions. Besides, since it is an application, data utilization could feed learning management systems to improve the educational process. In addition, certain usability aspects, such as app inconsistency, should be considered so that emotions do not negatively affect students in their learning process.

It is recommended that future studies make improvements in the application and expand the sample under investigation. It is also recommended to compare results between students using traditional laboratories in university facilities, those using the AR application in university facilities, and those using the AR application as a remote laboratory at home with the online support of an academic. The findings also open new lines of research, a product of the fact that the perception of inconsistencies in a system has an average relationship with hopelessness. These findings could encourage academics and educational institutions to incorporate augmented reality technology into their training processes.

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FIGURE 1. Diagram of the process of this study

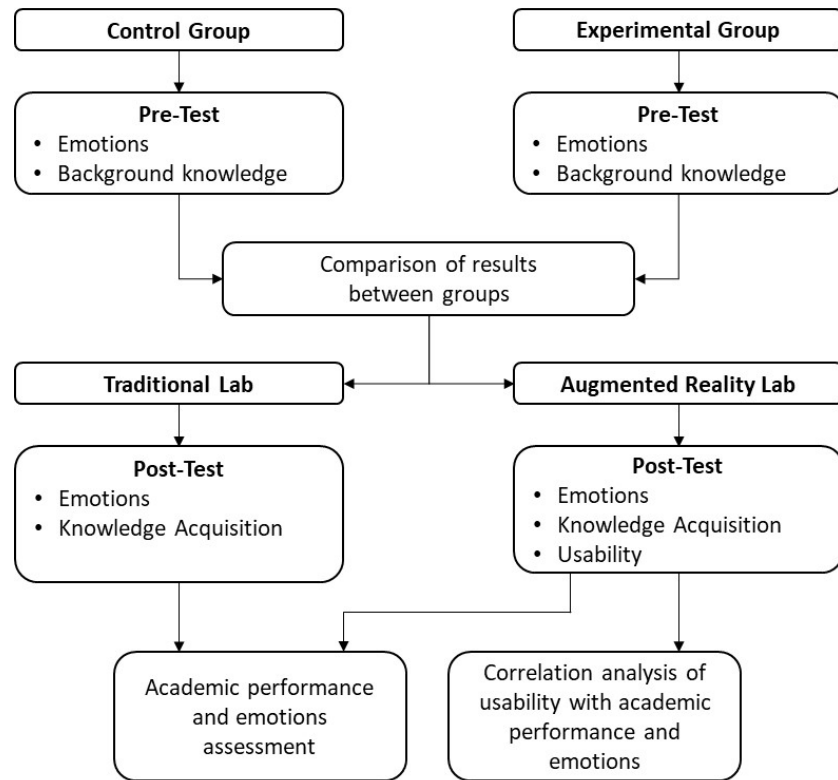


TABLE 1. PREVIOUS AR-BASED ENGINEERING EDUCATION RESEARCH

Variable Measured	# of studies
Perceived usefulness	23
Academic performance	17
Satisfaction	16
Usability	15
Motivation	14
System quality	8
Facilitating conditions	6
Interaction	6
Aesthetics	6
Information quality	5
Perceived enjoyment	2
Technology acceptance	1

Note: $N = 39$

TABLE 2. DESCRIPTIVE STATISTIC OF KNOWLEDGE ACQUISITION

Variable	Control group (N=10)		Experimental group (N=18)		EG vs. CG
	Mean	SD	Mean	SD	Sig. test
KN_B	2.10	1.20	2.39	1.14	0.27
KN_A	2.40	1.26	4.17	0.62	0.00 *

Note: * Wilcoxon test. Significant differences are marked in bold. KN_B: Knowledge acquisition before; KN_A: Knowledge acquisition after.

TABLE 3. EMOTIONS BEFORE AND AFTER EXPERIENCE

	Control group			Experimental group		
	Before	After	p-value	Before	After	p-value
Anger	2.50	2.80	0.24	2.54	2.94	0.13 *
Enjoyment	3.10	3.00	0.40	2.89	3.24	0.14
Hopelessness	2.65	2.78	0.37	2.86	2.72	0.34
Anxiety	2.70	3.45	0.03	2.85	3.56	0.01
Shame	3.30	3.07	0.34	4.11	2.89	0.00 *
Pos_emo	3.43	3.13	0.17	3.34	3.33	0.41
Emo-a_neg	2.83	3.11	0.18	3.17	3.13	0.44
Emo-d_neg	2.83	2.78	0.44	2.99	2.72	0.19

Note: * Wilcoxon test. Significant differences are marked in bold. Pos_emo: Positive emotions; Emo-a_neg: Activation negative emotions; Emo-d_neg: Deactivation negative emotions.