

## EYE-TRACKING INDICATORS OF EMOTIONS DURING PROBLEM SOLVING

### ABSTRACT

Emotions, especially stress, affect a student's intellectual functioning, achievement and effectiveness in problem solving. Sources of stress include new and difficult situations in which there is frustration, essentially the set of unpleasant emotions associated with the inability to implement necessities or the difficulty in solving a task or problem. The reaction to stress is often an escape from the frustrating situation or resignation, which in the case of learning leads to a reduction of effectiveness. Therefore, an important aspect of teachers' work is helping students to relieve stress and maintain their motivation to learn. This is particularly essential for school subjects that are generally considered by students to be difficult. This article discusses the results of studies in which the eye-tracking technique was used to identify emotions, especially stress, experienced during problem solving in physics, mathematics, computer science and biology. In this experiment, eye movement parameters and survey data were analysed with the aim of obtaining information on the subjective assessment of the stress level experienced during problem solving in the field of science. Participants included 45 pupils (middle school students). The results confirm the possibility of using eye-tracking data to diagnose negative emotions. The results of the studies might also be useful for teachers, who might be able to design a system of rapid intervention and student support, with the goal of stopping students from a quick resignation of solving problems. This study fits into the new trend of neurodidactics for the development of interdisciplinary research in the area of teaching.

**KEYWORDS:** *eye-tracking, neurodidactics, eye movement parameters, educational research, emotions*

## INTRODUCTION

### *Neurodidactics – a new trend in educational research related to technology development and cognitive research*

Recent decades have brought the development of new technologies, as evidenced, among other things, by an increased availability of research equipment for social and humanities sciences, which had previously been used mainly in medical science. There has been a huge increase in knowledge about the functioning of the brain. Interdisciplinary research conducted on the borderline of neurology, psychology and pedagogy (teaching in particular) has contributed to the emergence of a new discipline – neurodidactics. Among other things, this young science addresses the neurobiological aspects of the learning process, and it uses knowledge about the functioning of the brain to increase the efficiency of learning and improve teaching methods (Sabitzer, 2011).

Analysis of the data obtained from experiments carried out by scientists worldwide using active brain imaging techniques and EEG, MEG, PET scan, and fMRI allows for a better understanding of cognitive ability, including the selection process and memorizing information, directing attention, and reacting to new situations (problems, tasks). Based on the research on the brain, new teaching strategies are being developed, implementing knowledge that is not necessarily new but has been verified by experimental research.

The high potential for research in neurodidactics is highlighted by the German professor of music education W. Gruhn (2004, p. 1–8), who writes that *‘with knowledge about electrochemical and hormonal processes that enhance synaptic strength and facilitate long-term representation that can be re-activated at any time, methods and teaching strategies (= didactics) as well as the organization of environmental sets for teaching and learning, curriculum development and school policies can be related to the developmental state of the brain and its neurobiological conditions’*.

Americans K. Muldner and W. Bursen (2015, p. 127–137) promote a new trend of research related to exploring the utility of various sensing devices, including an eye tracker, a skin conductance bracelet, and an EEG sensor, for modelling creativity during an educational activity.

Neurodidactics also involves the study of the impact of stress on the different types of memory and learning processes, including operational functions.

## REVIEW OF THE RELEVANT LITERATURE

### *Emotions in the educational process*

Many researchers stress the importance of creating a friendly environment for teaching and learning. Taking into account the impact of students' state of mind on developed and implemented teaching strategies is recommended by, among others, G. Caine and R.N. Caine (2014, p. 1–43). According to Caine and Caine, *'explicit directions, clear explanations, and enough practice and rehearsal to ensure memorization of facts and routines can work in two different ways. On the one hand, they can provide clear structures and opportunities for success that together generate a sense of safety, allow learners to feel relaxed and competent, and so build foundations for high level performance. On the other hand being told what to do and rote memorization of stuff that is meaningless can be hugely frustrating and depressing. When this is accompanied by the sort of discipline that makes the learners' interests and concerns irrelevant, and pays no attention to what they actually need, the survival response is triggered'*.

Experimental studies utilizing functional magnetic resonance imaging (fMRI) show, for example, that the emotional context of learning (both positive and negative) is very important for the memorization process (Erk et al., 2003, p. 439–447). As an example, information bearing emotional context is memorised more easily than neutral information. Erk and others proved that storing words embedded in a positive emotional context caused activity in the hippocampus and the parahippocampus, i.e., in areas related to learning and memory. In contrast, when words were encoded under a negative emotional context, the amygdala was active (Erk et al., 2003, p. 439–447). The amygdala is responsible for identifying situations that cause stress and assigning them emotional significance. Excessive activation of the amygdala leads to inhibition of the hippocampus; thus, in effect, stress affects the learning process by inhibiting it. Krauzowicz J. (2013, p. 84–92) writes that experimental studies have shown the important functions that positive emotions play during stressful situations. Under the influence of

positive emotions – joy, contentment, pride and humour – the range of processes involved in solving problems, such as attention, memory, and thinking, is increased, and one becomes more flexible, creative, and more easily able to build intellectual resources. Related to this is the research conducted by Frederickson, which showed that positive emotions have the ability to reverse the physiological effects of negative emotions (Fredrickson, 2004, p. 1367–1377).

### **STRESS IN EDUCATION AND ITS IMPACT ON THE EFFECTIVENESS OF LEARNING**

People react to stress in various ways. Some are seized by fear and depression, break down and cannot face adversities. Others, who are more resistant, are able to survive stressful situations and even turn a failure into a success. An explanation for these differences can be understood by accepting the notion that different people experience different emotional states (Davidson and Begley, 2013, p. 21–24).

Knowledge resulting from neuroimaging of the brain is not taken into consideration in contemporary Polish education. Verification of students' knowledge by testing is a popular and widely used method of evaluation and the teachers expect reliable, uninterrupted, undistorted results, which represent the actual state of knowledge and competence of students.

The reliability of the test results might be distorted by fear. The basis for this fear might be the fear of receiving a negative assessment. Spitzer (2006, p. 47–62) believes that fear produces a certain cognitive style that facilitates the execution of simple learned routines but at the same time, blocks creativity.

Stress experienced during knowledge testing can cause different reactions. Cognitive processes such as perception, attention, memory, and information processing can be weakened in people under prolonged stress; in contrast, during the initial changes of stress, mobilization occurs, increasing the efficiency of intellectual and cognitive processes (acceleration of thought processes, improved memory efficiency and associations) (Krauzowicz, 2013, p. 84–92). Identification of the student's emotional state is highly relevant in the learning process and can occur by observing the behaviour of students or the registration of biological signals.

## THE USE OF BIOLOGICAL SIGNALS TO IDENTIFY STUDENTS' EMOTIONAL STATES

One non-invasive method for evaluating brain bioelectrical activity is electroencephalography (EEG). In recent years, there have been a number of studies that aimed to detect different emotional states based on EEG signal analysis (Hatamikia et al., 2013, p. 194–201). In order to recognize emotions, electrocardiography (ECG), a diagnostic procedure used in medicine primarily to recognize heart disease, can be used. Emotional states can also be identified by physiological measures such as electromyogram (EMG), galvanic skin response (GSR), blood pressure (BP), and skin temperature (ST). Researchers have also attempted to build their own measurement systems. Analysis of the data obtained in the experiments is complicated and often requires the use of advanced algorithms, and non-linear analysis based on chaos theory helps in identifying the apparently irregular behaviours (Selvaraj et al., 2013, p. 1–18).

Emotional states can also be detected by systems that measure eye motion and reaction parameters. Although in recent years the dominant research seems to focus on measuring teaching effectiveness and analysis of patterns of information processing during the process of learning (Stolińska et al., 2014, p. 7–20), at the same time, numerous explorations related to the identification of emotions have been undertaken. Identification of emotions during the process of learning is particularly important for the design of personalized, adaptive systems supporting e-learning and Intelligent Tutoring Systems (ITSs). Construction of such measures has been undertaken by, among others, W. Burlison (2006, p. 11), the Founding Director of the Motivational Environments research group. The researcher constructed the multi-modal sensor system, which consists of a Pressure Mouse, a wireless Bluetooth skin conductance sensor, a Posture Analysis Seat, a Facial Action Unit analysis using the Blue Eyes camera system, and head tracking. Similarly the work of N. Jaques et al. focuses on predicting feelings of boredom and curiosity experienced during learner interactions with MetaTutor, an ITS designed to support effective self-regulated learning (Jaques, 2014, p. 29–38). They write that findings from psychological research have suggested that blinking often or a lack of fixations on interface text may help predict boredom Smilek et al. (2010, p. 786–789) and that increased pupil diameter may be indicative of

stronger emotion.

Muldner et al. (2009, p. 138–149) undertook research in which they analysed pupillary data for informing a user model on high-level user states related to affect and reasoning style. S.P. Marshall (2007, p. 165–175) at Ohio State University carried out emotional state identification based on eye-tracking measurements. The research focused on identifying emotions with an eye tracking device. M. Alshehri and S. Alghowinem (2013, p. 428–433) observed that *‘fixation count was significantly different between pleasant and unpleasant stimuli. With the present finding, fixation seems to hold discriminative emotional effect in pleasant and unpleasant stimuli. Taken together, these results suggest that further research of fixation to detect different emotional states is needed.’*

For many reasons, eye-tracking is a non-invasive method that can be used to examine the state of emotional and cognitive processes. Comparing this information with the results of studies indicating that the presence of an empathetic and supportive tutor or pedagogical agent has been shown to enhance learning and reduce stress (Prendinger and Ishizuka, 2005, p. 267–285), it is legitimate to draw attention to the possibility of using eye-tracking techniques to identify frustration and those at high-risk of resignation from problem solving.

The aim of the study was to find oculomotor correlates of stress experienced by the student in the course of problem solving.

## METHODOLOGY AND METHODS

### *Participants*

Data from the 45 participants in the experiment (middle school students) were used for the analysis. Data from 7 subjects was excluded due to inadequate eye gaze data. Fifteen students were participants in competitions in the field of science and (or) natural sciences (Competition group), and the remaining students (30 persons) were assigned to the group of ‘Non-competition students’. All the subjects had normal or corrected visual acuity.

### *Procedure*

This study was conducted in the eye-tracking laboratory and consisted of three stages: first, students were interviewed by a person conducting the experiment, and the course of the experiment was described. How the eye

tracker works was explained, and anonymity and confidentiality were ensured. Completed questionnaires were not available to those outside the research and analysis team, and only quantitative and statistical data would be available to others. The aim of the interview was to motivate students to fully engage in solving the problems and also to reduce stress caused by participating in the experiment. Students were asked to attempt to solve each problem and give up only if they were sure about the ineffectiveness of the actions taken. After the interview, each student sat at the computer station with an eye-tracking device. After calibration, they began problem solving. On the computer screen, slides with problems of different levels of difficulty were presented. No problem required the use of pen and paper; all the necessary calculations could and should have been done by memory. After students indicated the number of the correct answer, another slide was displayed. The time spent on solving specific problems was not limited. In the third stage of the study, students completed a survey that evaluated, among other things, the level of difficulty solving problems in the previous part of the research and the level of stress experienced during each stage of the research as well as during problem solving.

### *Eye tracking apparatus*

An advanced SensoMotoric Instruments iViewX™ Hi-Speed500/1250 eye tracker (company SensoMotoric Instruments GmbH, Germany), recording a stream of data with 500 Hz time resolution, was used; the elements measured included coordinates (the x and y coordinates of the gaze position), pupil width (a relative and absolute measurement), and the parameters of saccades and fixations. The interface construction used in this system kept the participant's head still without limiting the field of vision. Calibration and other operations, which ensured the results obtained were reliable and non-distorted, were made before each test. The test was carried out with the same environmental conditions, including temperature, lighting and acoustic insulation, for all participants. Advanced data analysis was possible with the integrated SMI BeGaze™ 2.4 software.

### *Eye-movement parameters*

The device recorded dozens of parameters, which can be grouped into three

main characteristics: blinking, fixation (stopping eyesight at a specific location of the projected image) and saccadic movements (rapid eye movement, which aims at positioning the axis of vision in both eyes on selected items of the viewed scene). Although previous studies have suggested that attention should be focused on the parameter of blinking, in this study, the researchers also focused on fixations and saccades because, in contrast to blinking, these parameters are not dependent on external factors such as humidity.

## ***Results***

Students solved problems in the area of science, in the order presented below:

- 2 information technology problems (ALG1, ALG2),
- 1 biology problem (BIO),
- 3 physics problems (PHYS1, PHYS2, PHYS3),
- 2 mathematics problems (MATH1, MATH2).

### ***Assessment of the level of stress experienced during problem solving***

Immediately after the eye-tracking test, students filled out a questionnaire to assess the extent to which they felt stress while solving the problems, on a scale of 0 to 10 (where 0 – not stressful, 10 – very stressful).

Table 1.

**Assessment of the level of stress experienced during problem solving (N = 45)**

<b>Stimulus</b>	<b>Mean</b>	<b>SD</b>
ALG1	5.49	2.81
ALG2	5.71	2.88
BIO	4.18	3.24
PHYS1	3.09	2.84
PHYS2	3.60	2.78
PHYS3	4.36	2.81
MATH1	3.69	2.81
MATH2	3.96	2.74



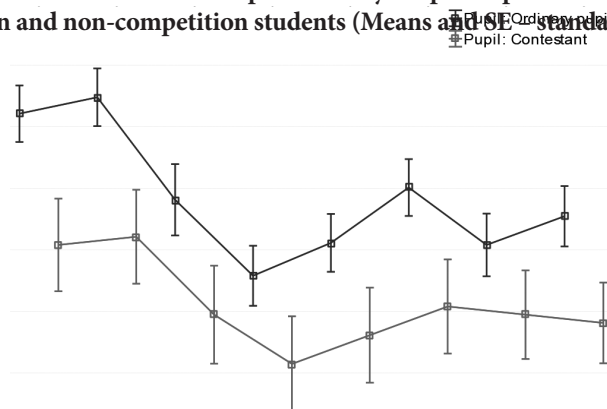
Source: own elaboration

The decision was made to use an odd number of possible answers to choose from, so that the middle statement marked by indicating 5 was the most neutral. To avoid mistakes, each problem was presented in the questionnaire in the form of a thumbnail of the original slide. Table 1 shows the mean values and standard deviations of the levels of declared stress in the 11-grade scale.

Comparing the level of declared stress in the two test groups – the non-competition students showed higher levels of stress in solving all of the problems than the competition participants.

Figure 1.

**Comparison of the level of stress experienced by the participants of Cracow Physics Competition and non-competition students (Means and SE standard errors)**



Source: own elaboration

For the purposes of this research, three problems from the homogeneous thematic group, PHYS1, PHYS2, and PHSY3, were selected for further analysis; according to the students, these three problems caused different levels of stress. Table 1 shows that the first two problems chosen for analysis were felt to be the least stressful. However, the third problem, after the initial IT problems, was regarded as highly stressful. These problems were placed in the middle phase of the experiment, after the students were familiarised with the apparatus and test procedure, so the perceived stress would be associated primarily with the presented problems. Moreover, for students in many countries worldwide, physics is one of the most disliked school subjects (Błasiak et al., 2012, p.565–571),

and this was an additional argument for choosing those problems.

### ***Oculomotor correlates of stress***

To assess relationships between the level of experienced stress and motion and reaction of the eyes, Pearson correlation coefficients were used to analyse basic eye-tracking parameters. Values were considered significant at  $p < 0.05$ .

### ***Blinking***

Table 2 shows the Pearson correlation coefficients for the blink parameters and the level of stress declared by the students in the following three groups: all participants ( $N = 45$ , the critical value  $R = 0.25$ ), competition participants ( $N = 15$ ,  $r = 0.44$ ), and non-competition students ( $N = 30$ ,  $r = 0.31$ ).

Table 2.

### **The Pearson linear correlation coefficients for selected parameters of blinking and declared stress**

	The values of the Pearson linear correlation coefficients (r)		
	Blink Count	Blink Duration Total [ms]	Blink Duration Minimum [ms]
PHYS1	0.28	0.28	-0.26
Contestant	0.34	0.26	-0.36
Ordinary Pupil	0.22	0.26	-0.10
PHYS2	0.31	0.29	-0.29
Contestant	0.65	0.55	-0.65
Ordinary Pupil	0.10	0.09	-0.10
PHYS3	0.32	0.28	-0.41
Contestant	0.54	0.37	-0.77
Ordinary Pupil	0.28	0.32	-0.206

Source: own elaboration

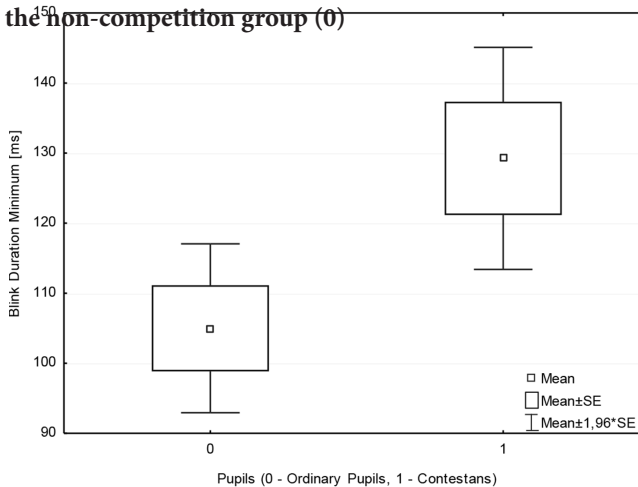
Based on these data, it can be concluded that there are correlations between subjective assessment of the level of experienced stress and Blink Count and Total Blink Duration. There was a negative correlation between stress level and Minimum Blink Duration, which indicates that as experienced stress increased, there was a decrease in the duration of blinks.

T test analysis revealed significant differences for the parameter of Minimum Blink Duration across all problems. This relationship is illustrated

in the chart below.

Figure 2.

**The mean Minimum Blink Duration – differences between the competition group (1) and the non-competition group (0)**



Source: own elaboration

## Fixations

Table 3.

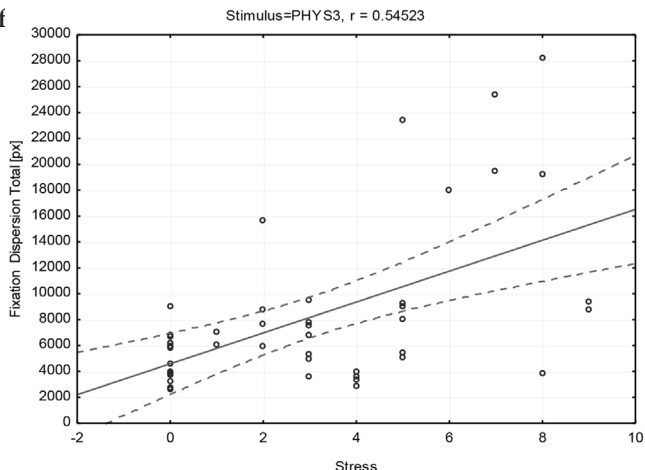
**The Pearson linear correlation coefficients for selected parameters of fixation and declared stress**

	The values of the Pearson linear correlation coefficients (r)			
	Fixation Count	Fixation Duration Total [ms]	Fixation Dispersion Total [px]	Fixation Dispersion Maximum [px]
PHYS1	0.49	0.51	0.41	0.30
Contestant	0.45	0.57	0.64	0.70
Ordinary Pupil	0.48	0.47	0.30	0.28
PHYS2	0.40	0.37	0.43	0.33
Contestant	0.50	0.50	0.61	0.29
Ordinary Pupil	0.35	0.29	0.41	0.34
PHYS3	0.32	0.33	0.55	0.31
Contestant	0.50	0.59	0.62	0.51
Ordinary Pupil	0.38	0.36	0.49	0.18

Source: own elaboration

For most parameters, the Pearson linear correlation coefficients were high, and for Total Fixation Dispersion, correlations were particularly strong. Significant p-values (under significance level 0.05) are marked with boldfaced font.

Figure 3.  
Scatterplot of the level of



Source: own elaboration

### Saccades

Table 4.

The Pearson linear correlation coefficients for selected parameters of saccades and declared stress

	The values of the Pearson linear correlation coefficients (r)				
	Scanpath Length [px]	Saccade Count	Saccade Duration Total [ms]	Saccade Amplitude Total [°]	Saccade Velocity Total [°/s]
PHYS1	0.46	0.52	0.50	0.43	0.41
Contestant	0.35	0.42	0.30	0.30	0.37
Ordinary Pupil	0.52	0.54	0.57	0.48	0.41
PHYS2	0.43	0.40	0.40	0.43	0.42
Contestant	0.46	0.46	0.43	0.46	0.48
Ordinary Pupil	0.46	0.38	0.43	0.48	0.40
PHYS3	0.30	0.33	0.30	0.34	0.34
Contestant	0.44	0.44	0.33	0.45	0.53
Ordinary Pupil	0.43	0.41	0.43	0.44	0.40

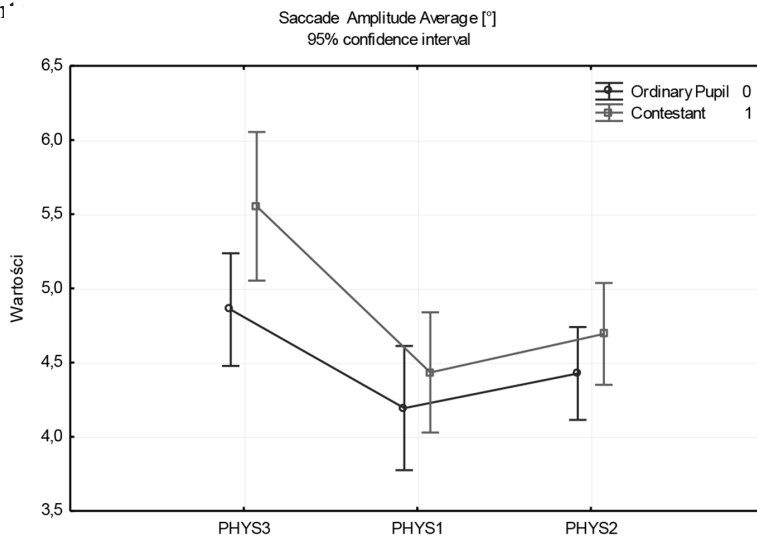
Source: own elaboration

Eye movement parameters that correlate with the level of declared stress are Scanpath Length, Saccade Count, Total Saccade Duration, Total Saccade Amplitude and Total Saccade Velocity. Of note, the results show stronger correlation between stress and the parameters of saccades for non-competitive students. This suggests that people with different levels of perceived stress and ability to cope with stress during problem solving might have different strategies for scanning the visual scene.

As seen in Figure 4, the average amplitudes of saccades for each of the tasks were greater in the group of competition students, which, as studies show, is a behaviour characteristic of experts in given field (Stolińska et al., 2014, p. 7–20). T-test analysis showed that the differences in saccade parameters between competition and non-competition students were statistically significant ( $p < 0.001$ ).

Figure 4.

**Graph of mean amplitudes of saccades for competition and non-competition student'**



Source: own elaboration

## CONCLUSION

Research has shown that the intensity of the emotional state described by the participants correlates with eye movement and reaction parameters during problem solving. Among the dozens of eye-tracking parameters, several correlate with noticeable levels of stress. These include Blink Count, Total Blink Duration [ms], Minimum Blink Duration [ms], Fixation Count, Total Fixation Duration [ms], Total Fixation Dispersion [px], Maximum Fixation Dispersion [px], Scanpath Length [px], Saccade Count, Total Saccade Duration [ms], Total Saccade Amplitude [°], and Total Saccade Velocity [°/s]. The results confirm the assumption made by M. Alshehri and S. Alghowinem (2013, pp. 428–433), who indicate that fixations might be indicators of emotional states, but the results of our experiment suggest that an extension of the collection of oculomotor correlates with the parameters of saccades. However, it is necessary to conduct further tests to verify the results while eliminating the impact of the specificity of tasks and external factors. Significant differences between the results of the two groups of subjects, competition students and non-competition students, also show the need for further research. It seems reasonable to suppose that the competition students were able to more accurately determine the feeling of stress induced by the problems than by other factors. Because the reliability of the subjective assessment of stress level is low (in the proposed scale), it is useful to carry out parallel measurements of other parameters of stress (Hatamikia et al., 2013, p. 194–201).

Fear of failure is an important barrier in the process of learning. Rational cognitive assessment, analysis of the situation and recognition of stimuli can significantly help to reduce stress (Spitzer, 2006, p. 47–62). A teacher who observes a negative effect of stress during problem solving can provide incentives that remove the undesirable effects of stress. It is likely that in the near future, this will allow for a significant increase in the effectiveness of teaching, especially in subjects that are generally considered very difficult. Construction of a teaching system that recognizes stress through eye movements, which collects information about students unobtrusively without disrupting students' work, is difficult but extremely useful and didactically valuable.

This research also confirmed the need to introduce the results of neurodidactics into the teaching programs of future teachers. With neuroimaging, it becomes possible to consider the educational process from the pupils' point of view and to better understand the processes, including the emotional ones, that go on in their minds. A good educational system should take full advantage of a student's natural brain potential, and it should also consider the factors that inhibit the learning process.

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