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IZVIRNI ZNANSTVENI ČLANEK

Wearables in the classroom - psychophysiology in education

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Abstract. The paper presents measuring instrumentation suitable for a classroom use and to study learning and teaching by means of objective measures. The basic types of instruments used in the classroom for different purposes are presented, such as determination of the students' well-being, assessment of their engagement in work, evaluation of differences in their motivation, relaxation, focus and attention when different teaching approaches are used. In general, instruments can be either wearable or desktop. The former are attached to students (or their teachers) in a school environment to measure their physiology (e.g. heart rate, respiration rate, skin conductance, skin temperature, heat flow, blood pressure, etc.), and the latter allow the study of the psychological correlation between educational and physiological measures in controlled laboratory conditions. Some examples are given from various physiological studies in the field of education in the Slovenian primary schools.

Keywords: wearables, psychophysiology, skin conductance, electrodermal activity, thermography, classroom

Merilniki v šolskem okolju – psihofiziologija v edukaciji

Prispevek predstavi različno merilno inštrumentacijo in merilne metode, ki so primerne za uporabo v šolskem okolju in s katerimi lahko z objektivnimi merami proučujemo učenje in poučevanje. Prikaže osnovno razdelitev merilnikov, ki jih v razredu lahko uporabljamo za različne namene, na primer za ugotavljanje počutja učencev, za ocenjevanje njihove motiviranosti, sproščenosti in pozornosti med podajanjem učnih vsebin, za primerjavo različnih pristopov poučevanja. V splošnem lahko merilnike razdelimo na prenosne in laboratorijske. Prvi so v realnem šolskem okolju nameščeni na učencih (ali njihovih učiteljih) in merijo fiziologijo (npr. frekvenco srčnega utripa, frekvenco dihanja, prevodnost kože, temperaturo kože, toplotni tok, krvni tlak), drugi pa v nadzorovanih laboratorijskih pogojih omogočajo študij povezav psiholoških in edukacijskih mer s fiziološkimi. V prispevku nanizamo nekaj praktičnih primerov iz različnih študij s področja učenja in poučevanja učencev v slovenskih osnovnih šolah.

1 INTRODUCTION

Psychophysical relaxation triggers biochemical processes in the brain. Endorphins are secreted, which results in a better well-being and greater motivation and ability. In the educational sciences, relaxation and calming enable a greater readiness for learning, higher acquisition of new knowledge and increase in the self-confidence, which altogether result in a greater efficiency of learning and teaching in the classroom. Psychophysiology studies the physiological responses of the body to psychological events. It is an objective measure to determine constructs such as relaxation, attention, calmness, stress, etc. In education, psychophysiology is used in studies of relaxation, psychological activation, evaluation of the impact of teaching methods on students, impact of mental stress in the school environment, in testing the social anxiety, etc. The impact of a psychological, cognitive or mental effort on the physiological parameters of a human is described in various studies [1]–[10]. Studies show that in a laboratory setting, mental, cognitive and/or emotional exertion can trigger a sympathetic nervous system response. Studies report the impact of stress on various psychophysiological parameters, such as changes in the heart rate and blood pressure, skin electrical conductance, skin temperature, pupil size, brain activity, facial muscle electromyograms, etc. Increases in the heart rate and in the systolic and diastolic blood pressure are reported during mentally stressful tasks. The other reported effects are changes in the skin conductance and skin temperature.

Of a particular interest are studies that are not performed in controlled laboratory conditions, but in real conditions, such as studies of the psychological stress imposed on students in a classroom, competing athletes, air-traffic controllers, as well as studies of the psychology of participants in education, road traffic, rehabilitation, etc [1]–[10]. Laboratory studies typically use a variety of the mental or emotional stimulus, such as the Stroop test, math tests, self-evaluation stress tests, etc. [7], [11].

In the educational sciences, various measuring instruments are commonly used to observe and evaluate the students' movement, physical activity and energy expenditure [11]–[15]. There are far fewer studies of

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observing the students' psychophysiological response, which would point to a neuropsychological aspect of learning [15].

In general, to assess the students’ and teachers’ activities, behaviour, effectiveness of their learning and teaching, the most commonly used parameter is the students’ physiology, e.g., heart rate and electrodermal activity (EDA). Other physiological quantities that can be measured non-invasively or even with no contact with students in a classroom are also used.

Figure 1. Measurement of the impact of performing demanding science tests on the student’s physiology - heart rate, skin conductance and finger temperature on a non-dominant arm, and respiratory [16].

The paper presents the typical and most commonly used physiological parameters to measure the psychological arousal of students in a classroom. Using such measurements, the students’ well-being, level of their motivation, activation, (dis) interest in a particular subject, etc. can be inferred. In addition, some examples are given of the use of physiology in physiological studies conducted in the Slovenian primary schools.

1.1 Psychophysiological quantities in education

One of the main goals of the educational sciences is effective learning and teaching. We are interested in the well-being of students and teachers (whether they feel comfortable, calm, distracted, activated, stressed, anxious, etc.), their psychological activation (whether they are interested in the topic, their level of expectation of new knowledge, etc.), their level of motivation (do they want to learn, are they motivated to learn something new), etc.

In studying the students’ well-being physiological parameters are used. They are usually the correlates of the autonomous nervous system activity. Different measurement methods are used to measure and interpret them according to experimental hypothesis (e.g. whether the blood pressure level of a reading student can say anything about the difficulty of the read text).

Due to the measurements complexity, relatively large measurement errors (due to the loss of the electrode contact with the skin, failed data transfer, environmental extraneous disturbances, moving artefacts, etc.), and logistical and ergonomic reasons, studies typically use multi-parametric measurements, i.e. several (even redundant) quantities are measured simultaneously and thus the measured data are interpreted with a greater reliability (Figures 1 and 2).

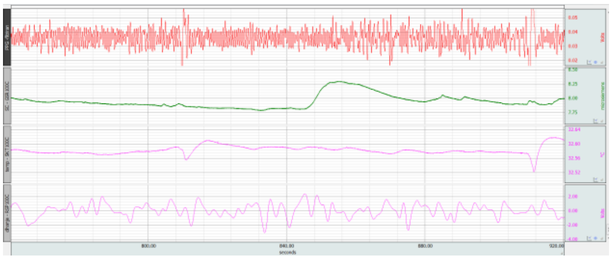


Figure 2. Time graphs of four physiological parameters of a student solving a biology test. Signals from above: blood flow oscillations (for determination of student’s heart rate), skin conductance between the last phalanges of the index and middle finger, fingertip temperature and respiration rate.

1.1.1 Cardiovascular parameters

Changes in the students’ psychological state are commonly strongly expressed in their circulatory system and dynamics of cardiovascular activity [1], [2], [7], [17], [18]. The heart rate and heart rate variability are the parameters that strongly correlate with the students' psychological state. With an increased psychological activation and stress, there is an increase in their heart rate, which can be measured in various ways. In a classroom, photoplethysmography (watches) or the ECG method (sports activity monitors with chest belts) are typically used.

Besides the heart rate, one of the basic cardiovascular parameters is also the arterial blood pressure. In psychophysiological studies, the blood pressure can be measured intermittently using oscillometry or auscultatory measurements, which makes the sampling frequency quite small. A typical sampling frequency is one measurement of systolic and diastolic pressure per one to a few minutes. This time interval is, of course, too large to be used in psychophysiology, so a continuous measurement is more appropriate, especially in a non-invasive form [19], [20].

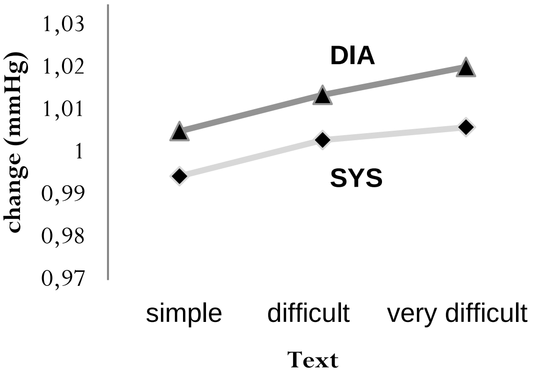


Figure 3. Example of using the blood pressure to determine the difficulty of a read text. The graph shows a change in a continuously measured blood pressure (SYS – systolic, DIA – diastolic) while reading texts of different semantic difficulty rates [21].

1.1.2 Electrodermal activity (EDA)

Measuring the electrical properties of the skin is one of the most widely used methods for observing the psychological arousal in humans [22]–[24].

EDA stands for all the electrical properties of the skin, mostly for the electrical response to the secretion of sweat. One of the properties is the skin conductance, the value of which changes with the activity of the sweat glands, correlating with the human psychological state. EDA consists of two components, i.e. the skin conductance level (SCL) and the skin conductance response (SCR). SCL describes the degree of the human psychological arousal, and SCR describes the phasic change in the skin conductance [22], [24]. Clinically, EDA is used in psychopathology, dermatology and neurology for diagnoses and evaluations of therapies, in psychology [22], [25], and increasingly also in education, as it is an affordable, technically simple methodology that is easily applicable in a school environment.

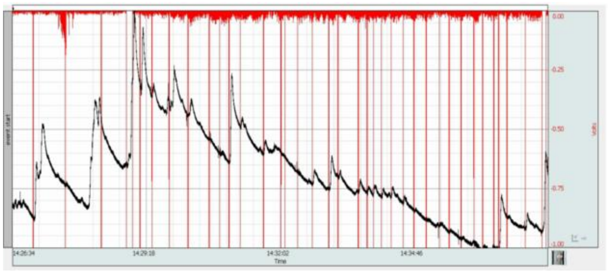


Figure 4. Relationship between the EDA level and solving mathematical calculations. The dark curve shows the EDA dynamics on the student's fingers while solving mathematical problems of different difficulty rates. The vertical lines indicate the start of solving a new calculation.

To be noted, EDA does not carry information on the valence, so it is not known whether an arousal is the result of a positive or negative experience, only the strength of the response is known. Therefore, in classroom studies, an additional valence measurement in parallel should be used, such as smileys on a five-point Likert scale, which are suitable also for younger children [15], [26].

The last phalanges of the index finger and middle finger, the middle phalanges of the index and ring finger, wrist, or other parts of the body (upper arm, inner arch of the foot) are commonly used as a site for measuring the skin conductance in classroom studies) [22], [27], [28]. It should be noted that the measured values may strongly depend on the measurement site (Figure 6).

Figure 5. Example of a physiological measurement in a classroom. A study of comparing different learning approaches. The students and the teacher wear wearables to measure their physical activity and psychological arousal (encircled) on their upper arms [29].

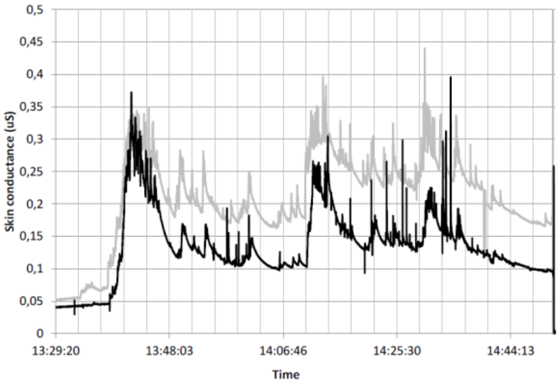


Figure 6. Example of EDA measurement on both upper arms of a student during a mathematics lesson. The difference in the absolute EDA value between the left and right hand is visible despite the similar dynamics.

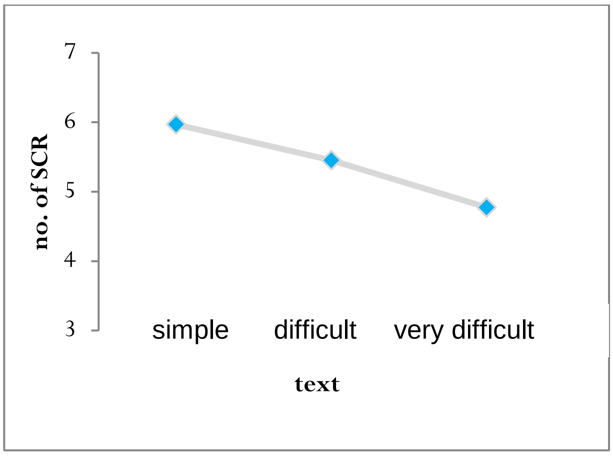


Figure 7. Example of using a number of SCRs to determine the semantic difficulty of a text. The graph shows the change in SCR while reading differently difficult texts [21].

1.1.3 *Skin temperature and body heat flux*

A series of studies examining changes in physiological parameters due to a psychological condition or stimulus find that the skin temperature is linearly dependent on the core body temperature [30]–[34]. Unlike the long-term thermoregulatory changes in the skin blood circulation due to cooling (vasoconstriction) and heating (vasodilatation), the change in the blood flow due to a psychological stimulus is short-lived. In a warm human having a typical finger temperature (33 ± 2) °C, a sympathetic stimulus causes vasoconstriction in the non-hairy part of the skin. These rapid temperature changes are usually measured on the skin (on the fingertip) using a fast-response thermometer (thermistor or thermocouple) or in a form of a thermographic measurement of a human's tissue.

Figure 8. Thermal image of a student during solving a mathematical test. As an indicator of the psychological activity, the student's nose is particularly interesting, and the difference between the temperature of the forehead and the nose is typically calculated.

A similar thermodynamic parameter is the heat flux, i.e. the radiated heat over a certain skin surface (unit W/m^2). The action is similar as with the temperature, i.e. the higher the psychological arousal, the greater the heat-flux decrease.

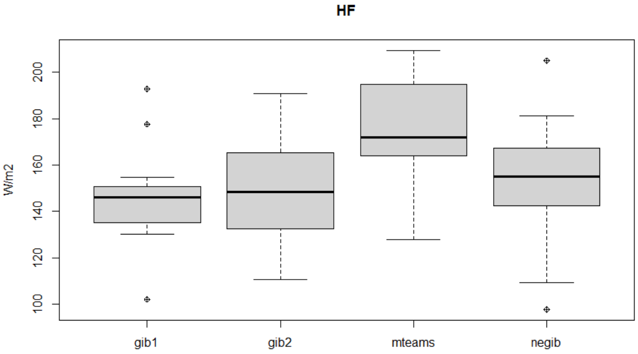


Figure 9. Comparison of the measured heat flux (HF) values on the students' upper arm when taught science at four meetings with three different teaching approaches (kinaesthetic approaches ("gib1" and "gib2"), distance learning ("mteams") and classical sedentary approach ("negib"). Judging from the results, the students are most relaxed in the kinaesthetic approach and least in distance learning [35].

1.1.4 *Respiration rate and other physiological measurements*

The respiratory-rate measurement is one of the psychophysiological methods that is less used in the classroom due to its demanding logistics [36]–[38]. The measurement method includes observation of exhaled air (by measuring the air temperature using a fast thermistor and by measuring the relative humidity of exhaled air using a fast hygrometer) or various (contact and non-contact) gauges of the chest movement. Installation of such gauges is time consuming and very intrusive, so it is predominately used in studies in laboratory conditions and rarely in a classroom.

Other non-invasive measurements include various techniques to observe the electrical or magnetic brain activity (EEG, MEG, fNIRS, fMRI) [39], [40]. As to the detection parameter, the methods are divided into those that directly measure the electromagnetic activity of triggered neurons (EEG, MED) and those that indirectly measure the activity of the triggered neurons through a blood flow (NIRS, MRI). As to the mode of operation, the methods are divided into passive and active. The active methods affect the brain and its activity can only then be measured (e.g. magnetic field stimulation in fMRI and MRI, injection of radioactive organic molecules in PET, light stimulus in fNIRS, etc.). The passive methods detect only the electromagnetic activity of the triggered neurons. In a school environment, these methods are almost non-existent as they are all very intrusive and not suitable for an in-situ measurement. Nevertheless, some simple wearable EEG and fNIRS monitors that measure attention and relaxation can also be used in education [41], [42].

1.2 Physiological instruments in education

Under laboratory conditions, the psychophysiological research is conducted in controlled environmental and experimental conditions. The laboratory instrumentation is accurate, reliable and robust, but th elaboratory conditions are not equivalent to (much less controlled) conditions in a real school environment.

The wearables, i.e. portable instruments, enable real-time measurements in real conditions even outside the laboratory. As a result, their measurements are more subject to external impacts they suffer from a higher measuring error, they are affected by a mental and cognitive state of a student, sociological interaction between students and between a student and a teacher, etc. On the other hand, their ergonomics, low power consumption, and small size allow the measurement's psychological effect of on a student to be minimized. Such minor intrusiveness of wearables reduces the measuring anxiety of students, i.e. a change in their physiology because of the awareness of being observed/measured [43], [44].

Figure 10. Measurements of the student's well-being while solving a computer-based school test in distance learning. A student uses a computer mouse, equipped with electrodes (encircled) to non-intrusively measure the student's EDA.

In a classroom, given the complexity of events and the consequent extremely demanding interpretation of results, several physiological and other parameters are typically measured simultaneously. This allows for a more reliable and firm conclusion (e.g., if a student's skin conductance increases while the finger temperature decreases, there is a high probability that the student is psychologically aroused).

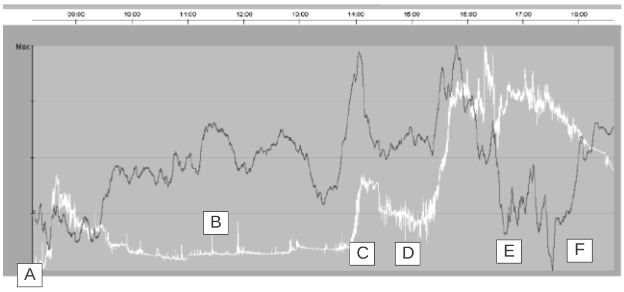


Figure 11. Skin temperature (dark signal) and skin conductance on the upper arm (white signal) in a school day of a seven-year-old child (A - start of class, B - class, C - lunch, D – afternoon class, E – football practice, F - theatre). A greater psychological activity is observed at the beginning of a class, when going to lunch and at the physical activity and smaller towards the end of the day while watching a theatre performance.

The complexity of classroom studies increases also when the physiology and other parameters of a number of students in a class are measured at the same time. Recently, studies of synchronization, interaction between the students' and the teacher's physiology, have been published [45]. A larger number of the measuring instruments means more information about what is happening in a classroom, but also a greater possibility for measurement errors, unresponsiveness, errors due to the environmental conditions, connection to the central unit, etc.

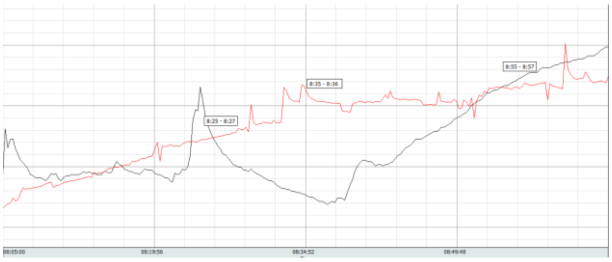


Figure 12. Comparison between the teacher's (dark curve) and the 25 students' EDA signal (light curve) during a lesson [35].

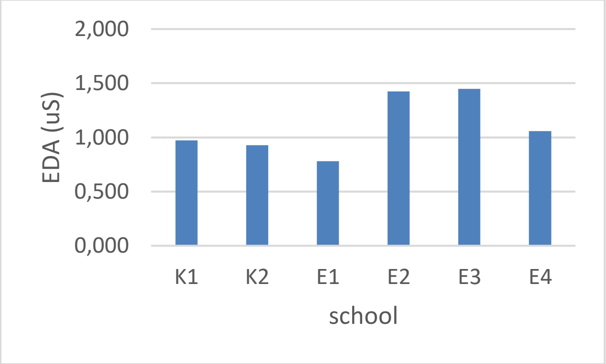
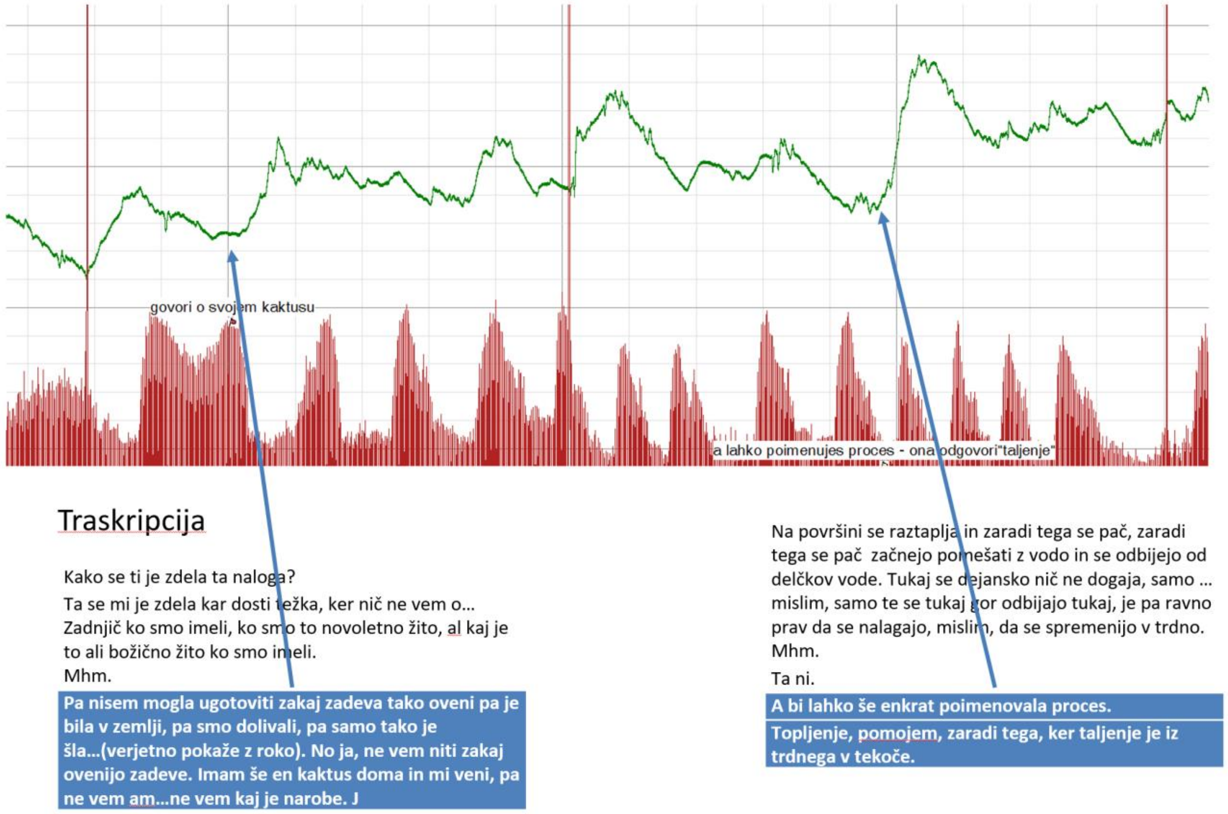


Figure 13. To ensure a higher validity of the study, much more statistical power is needed, which in turn means many more students to be measured. The graph shows an average EDA during a geometry lesson in six different Slovenian elementary schools (104 second-graders in total) [15].



Traskripcija

Kako se ti je zdela ta naloga?

Ta se mi je zdela kar dosti težka, ker nič ne vem o... Zadnjič ko smo imeli, ko smo to novoletno žito, al kaj je to ali božično žito ko smo imeli.

Mhm.

Pa nisem mogla ugotoviti zakaj zadeva tako oveni pa je bila v zemlji, pa smo dolivali, pa samo tako je šla...(verjetno pokaže z roko). No ja, ne vem niti zakaj ovenijo zadeve. Imam še en kaktus doma in mi veni, pa ne vem am...ne vem kaj je narobe. J

Na površini se raztaplja in zaradi tega se pač, zaradi tega se pač začnejo pomešati z vodo in se odbijejo od delčkov vode. Tukaj se dejansko nič ne dogaja, samo ... mislim, samo te se tukaj gor odbijajo tukaj, je pa ravno prav da se nalagajo, mislim, da se spremenijo v trdno.

Mhm.

Ta ni.

A bi lahko še enkrat poimenovala proces.

Topljenje, pomojem, zaradi tega, ker taljenje je iz trdnega v tekoče.

Figure 14. Example of a psychophysiological study of the student's physiology during a written Science test. The upper curve shows the time dynamics of the student's EDA signal, and the lower curve the students oral commenting. A notation (transcript) of the student's comments is added below. The arrows highlight two events that contribute to a sudden rise in the EDA value.

1.2.1 Environmental conditions in the classroom

Environmental conditions in educational studies are important to ensure a controlled environment and consequently a more reliable result interpretation. It is important to measure the environmental parameters, sometimes even control them (e.g. by air conditioning, electromagnetic or sound insulation of the classroom, etc.). In psychophysiological studies conducted in a classroom, monitoring the classroom temperature and relative humidity is important, the relative humidity is especially critical when measuring EDA). In addition, there are important parameters that can directly affect the students' concentration, motivation and performance, e.g. room lighting, acoustic noise, carbon dioxide concentration in air, etc. [15].

2 CONCLUSION

Studies in education explore learning and teaching, students' learning styles, their well-being, inter-connections, social interactions, study the effects of learning approaches, etc. Researchers are interested in the students' behaviour, their psychological state (relaxation, motivation, focus, cognitive effort, emotions, etc.), their physical state (level of movement, energy expenditure, kinematics, etc.) and cognitive activity (solving performance, difficulty of tasks, memory, etc.). As these are extremely complex topics, researchers use objective measurement methods combined with observational methods and psychological measuring instruments (questionnaires, interviews, etc.). Changes in the activity of the students' autonomous nervous system are also measured. By measuring the students' heart rate, skin conductance and temperature their psychological activation, arousal can be inferred, meaning that the correlation between the observed parameter and the students' physiology can be determined.

The physiological measuring instruments used in classrooms can be divided into i) contact-based, using electrodes attached to the student's body, and non-contact-based, measuring at a distance (e.g. thermal imaging camera, eye tracker, non-contact heart rate monitor), and ii) non-intrusive and intrusive.

Ina research applying psychophysiological measures, the following phenomena can be examined: i) the impact of teaching on a student and the students (type of teaching approach, monitoring of the students' well-being, difficulty of the topic), ii) the impact of teaching on teachers (relaxation, motivation, burnout, synchronization with students), iii) the impact of learning aids on students (special chairs, use of technology, virtual reality headsets, advanced ICT solutions, distance learning), iv) the impact of the classroom environment on the learning efficiency (lighting, noise, temperature, relative humidity) [15], [16], [18], [33].

Based on results of a physiological study, the school space can be improved by considering the impact of the classroom window placement, ventilation, colour and intensity of lights, air odour, etc., thus contributing to a more efficient learning and teaching process. In the future, physiology should be duly considered in the learning-teaching process, for example, by providing teachers with an efficient feedback, obtained by means of a physiological identification of unmotivated students, giving the teachers a signal to re-motivate their students.

With the integration of psychophysiology into schools, the ethical issues of the sensory instrumentation used in the classroom should be addressed.

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