Novel Methods for Integrating Personal Physiological Devices in STEM Education

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Keywords: IoT, Personal Physiological Devices, Motivation, BPMN, STEM, ECG.

Abstract: STEM education employs a variety of computer-based methods to improve motivation, personalization, and the quality of learning and instruction in the STEM disciplines. However, STEM educators and researchers often lack the knowledge and skills to integrate Internet of Things (IoT) and emerging personal physiological devices (PPDs) to enhance STEM education research and practice. The number of smartwatches, bands, and other PPDs has been expanding but research has so far failed to keep pace with the application of these technologies in education. The concept of STEM (the academic and professional disciplines of science, technology, engineering, and mathematics), adopted by Ukraine for 2020-2027, highlights the necessity to develop such efforts in Ukraine. The use of PPDs in STEM education research and practice may contribute to the introduction of STEM practices to students in Ukraine. To advance our understanding of integrating PPDs in STEM education, we have developed 13 new methods that facilitate the use of PPDs in STEM courses and educational research. We used a variety of inexpensive and widely used devices to test our proposed methods. Our team was probably the first one to apply the process mapping approach of "As Is – To Be" in educational research using the Business Process Model and Notation (BPMN) method to evaluate changes in educational processes before and after using PPDs in Biology classes from both pedagogical and technological points of view.

1 INTRODUCTION

The US National Science Foundation developed and disseminated the acronym "STEM" in 2001 to replace "SMET". As a separate area of didactics, STEM stood out in the USA in 2009 with its "Educate to Innovate" program. However, in Ukraine, STEM use is still in its infancy. However, its use is much less compared to the traditional educational approach (Shapovalov et al., 2020) even contrary to its advantages. A key focus in STEM education has been on increasing the engagement and motivation of students to take up STEM (Azevedo, 2015; Belland et al., 2013). Furthermore, STEM courses are designed to facilitate the development of 21st century learning and digital citizenship skills such as communication, data processing, and project management, all of which largely depend on informed use of information technology (International Society for Technology in Education (ISTE), 2023; Battelle for Kids, 2019). Significant attention in STEM is dedicated to increasing the students' motivation.

The main factor in forming the STEM is the growing demand for well-prepared and qualified STEM professionals thus contributing to the increasing em-

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Shapovalov, V., Shapovalov, Y., Bilyk, Z., Antonenko, P., Usenko, S., Zhadan, S., Lytovchenko, D. and Postova, K.
Novel Methods for Integrating Personal Physiological Devices in STEM Education.
DOI: 10.5220/0012067400003431
In *Proceedings of the 2nd Myroslav I. Zhaldak Symposium on Advances in Educational Technology (AET 2021)*, pages 733-750
ISBN: 978-989-758-662-0

phasis on STEM in education. STEM professions require non-routine problem-solving skills and design and implementation of solutions to the current science, engineering, and design challenges for our society. Other factors have also contributed to the increased interest of educators, researchers and policy makers in the STEM approach within education. For example, there is a need to transform instructional methods in the educational space from more teacher-centered approaches (the sage on stage) to more content and student-focused active learning approaches (Freeman et al., 2014).

STEM education tools may be classified into instrumental measurers, software, and modern perspective, but not widely used tools. In turn, the instrumental measurers can be divided into digital laboratories, digital equipment, mobile phones, mobile phones with additional sensors, and intelligent devices. Software like graphical calculators, modelling environments, games and simulations, VR video, VR and AR (Azevedo, 2015; Belland et al., 2013; International Society for Technology in Education (ISTE), 2023; Battelle for Kids, 2019), 3D printing, 3D modelling tools (Almusawi et al., 2021), and so on. One of the promising modern tools without widespread use is the usage the Internet of Things (IoT) that has high untapped potential in education due to several advantages, such as using cloud computing as well as computation and visualization of data measured or captured by measurers. In addition, those devices connected to the personal ecosystem provide personalized data.

Internet of Things (IoT) can use cloud servers for data processing and storage. Internet of Things includes the M2M (machine-to-machine) connection method for measurement and interaction requiring no human involvement.

PPDs can be considered as part of the IoT that have automatic algorithms for processing information and notify about a specific user parameter change. PPDs such as IoT are electronic devices connected through the Internet or Bluetooth and NFC. They send measured (fixed) data into the cloud, where such data is saved. Users can get information using the cloud from any place using an Android/iOS application or web interface. The main advantages of its use is personalization (the personal connection of the device to the personal page of the application/web interface). Distinctive features of PPDs as smart tools are:

- Measurement of actual real-time data
- Processing of measured data and obtaining calculated indicators
- Analysis of the data to state changes or to display an important to the user parameters.

PPDs include fitness bands (tracks), smartwatches, smart scales, and smartphones. Smartwatches/bands, scales, temperature sensors, humidity sensors, and specific plant sensors possess most promising potential for use in the education process (Gubbi et al., 2013). Personal physiological devices (PPDs; or personal smart tools) possess most promising potential for enhancing the student learning experiences in STEM education courses.

The relevance of the research is substantiated by the increase in the number of personal wearable devices due to their much higher affordability and simplicity (Pal et al., 2020). There was an expected jump from 100 million in 2016 to over 373 million in 2020 (Laricchia, 2022) and even up to 1.1 billion in 2022 due to the transformation of mobile internet connection from 4G to 5G (Visual Paradigm, 2016).

2 METHODS

The study was conducted using the methods of theoretical and empirical research. Firstly, analysis and synthesis were used to determine the main trends in the use of PPDs in education. Next, a comparative qualitative analysis was conducted to examine and compare the best pedagogical practices using PPDs. The cultural-system analysis and synthesis also have been used to build a theoretical model of as is-to be process. The following devices were used for proving our experiments: Colmi band 1, Xiaomi mi band 4, Samsung Smart Fitness Band, and Xiaomi Mi Smart Scale 2.

To analyze the proposed teaching process modification, the use of “As is-to be” method (Next Generation Science, 2023; Common Core, 2011) was the first necessary step. This method uses the Business Process Model and Notation (BPMN) (Guest, 2007) to note the current process and the proposed approach for both technological and pedagogical process business analyses. BPMN provides a decomposition of the complex processes into simple elements and connects them by arrows to interpret the total process. Additionally, BPMN uses “lines” to decompose elements of the process by the executor, for example, teacher and student.

In general, BPMN is used in business analysis. Still, considering its specifics, it will be suitable for use in scientific work to justify the practicality of using proposed educational approaches. Besides, very few researchers have used BPMN to describe processes in education (Nechypurenko and Soloviev, 2018; Cabinet of Ministries of Ukraine, 2020).

Hotline (https://hotline.ua/) web-market and its filters were used to evaluate the characteristics and existence of devices that can measure the exact parameters.

3 RESULTS AND DISCUSSION

3.1 Existing IoT and PPDs ecosystems

The most popular devices are part of a smart home and are connected using Wi-Fi or Bluetooth protocols. The most common devices are scales, watches, and fitness trackers. The leading manufacturers of these products are Samsung, Xiaomi with Amazfit/Huami sub-brands, Apple, Google Nest and others.

Samsung smartphones can become a central link within the entire ecosystem. From a phone, one can control watches, devices, and headphones, write some notes, and then continue working on them on the other device. At the same time, all synchronization is seamless. Internet availability is the necessary prerequisite for the entire system to work smoothly and as intended. Even without the Internet, one can exchange data between a tablet and a smartphone using Samsung Flow. The heart and brain of their developments are Bixby 2.0, an intelligent assistant that easily connects to Samsung devices. Bixby 2.0 is the central hub of the IoT ecosystem, learning from the daily interaction with users' devices to better understand and anticipate all needs of its user.

Today more than two hundred companies and start-ups are located under Xiaomi, each responsible for its product type. The Amazfit brand is developing fitness trackers and intelligent clock, and SmartMi produces intelligent home appliances. Wearing electronics has long since ceased to be a curiosity, and today it helps monitor physical activity, sleep quality, and overall health for millions of users worldwide. Xiaomi could not remain indifferent and, together with Amazfit, has found its niche in the ranks of intelligent wearable gadget manufacturers. It is no secret that Xiaomi Mi Band is one of the best and most popular fitness trackers. The fitness bracelet is improving its capabilities with each new generation and becoming more functional. Moreover, it maintains a reasonably loyal price tag thus ensuring the gadget's enduring popularity.

Nonetheless, the company is not in charge of wearable gadgets. Household medical devices, such as electronic thermometers, inhalers, and tonometers, have also found their place within the model ranges of the aforementioned Chinese technology giants. Recently, Xiaomi has begun mastering another area – home simulators. At the moment, among Xiaomi's simulators, one can find the WalkingPad A1 folding treadmill. There is no doubt that the company will also cover other sports equipment for home sports in the nearest future.

Apple HomeKit and Health app are the platforms, the central purpose of which is to unite all the smart technologies within one home. The HomeKit platform was released by Apple back in 2014 as part of the WWDC conference, and already a year later, full-fledged devices based on it became available for sale. Starting with the iOS 8 operation system, Apple mobile devices would be able to manage compatible home appliances and home life support systems. One of the advantages of HomeKit is close integration with the Siri virtual assistant. Home Kit can be controlled by voice commands, which opens up enormous opportunities for home appliance developers and software developers. A native application appeared in iOS 10 to replace third party software. The program was able to take over the management of all Smart Home appliances equipped with the appropriate software. Apple's Health app allows to monitor health and daily activity whilst providing important information to one's family or friends when needed. It is especially critical in the event of an accident or sudden illness and while tracking fitness stress. The app excellently works with Apple Watch. For example, Apple Watch can measure the level of O2 in blood and take electrocardiograms.

Google began taking its first steps towards a smart home back in 2016 when it introduced the first Google Home speaker. It is supposed to be an analogue of Amazon Echo, i.e. it can control home appliances and be used as a multimedia device. The Google Cast application, which is used to configure and manage Chromecast devices, has since been renamed Google Home. One of the latest innovations from Google in this field was the Google Home Hub, shown last year. Google Home Hub is a tablet with a display that can combine information about your smart devices in the Google Home ecosystem and display it on a built-in display. In 2019, Google presented its product Nest Hub Max at a presentation. Google's Home Hub had a camera and added multiplayer functions. Several operating tools of Google Nest are supporting Google Assistant. In addition to the devices produced and presented by Google itself, many companies manufacture devices compatible with this ecosystem. Their number has already surpassed 500. Each day, there are more and more manufacturers producing products marked "works with Google Assistant".

However, it seems relevant to analyze the ecosystems of those companies based on the parameters that can be measured by particular equipment. The main parameters used during educational research are heart rate, blood pressure, ECG, oxygen content, weight, muscle, fat, bone, and water content in the human body. Exa plus devices of different companies that can measure exact parameters are presented in table 1.

3.2 Analysis of Proposed Teaching Process Modification

PPDs are capable of providing a transcendent educational experience, meaning students can interact with objects directly. They investigate whether it is necessary by themselves. By using PPDs, students can perform different activities such as assessing the level of O2 in blood, heart rate, and more. To create an intelligent lesson, it is necessary to achieve connectivity between innovative tools and smartphones via specific applications, for example, Xiaomi Mi Fit.

During the "As is" for research, STEM-lesson process anticipates that the teacher explains the theory, sometimes challenging for students' understanding, with further explanation of parameters that will affect the object or function. In all cases, the teacher will explain an experiment using the class board without any research, less often by providing demonstrations, and, very rarely, by conducting a group experiment. In these cases, a student does not understand the material clearly. Moreover, skills and competencies delivered using this process will be limited only by a specific topic, laid down in the lesson, which may be insufficient according to the latest international and Ukrainian documents.

The technical part for all demonstrations and group experiments will be mostly provided manually by students or teachers. The results will be calculated, processed, and interpreted manually. This time can be used more beneficially for students' teaching process. Thus, measurement starts with choosing the measurer and providing measurement. Obtained data must be noted and written using a class board or worksheets. The calculation is provided manually, which may be more useful than automatic computation. The best effect may be obtained by combining both manual and automated analysis. Obtained data is interpreted in graphs, board, or worksheets. Finally, the graphics and data are analyzed.

Typically for the "As is" process, the teacher starts classes from the theory and further transfers to the more practically oriented part, explaining the factors affecting some object or function. Pupils will have demonstrations, group experiments, or personal experiments based on the available innovative tools. Understanding of the materials will be better due to the higher speed of the research. Calculation and graph creation will be provided automatically. Students will work with personal data and graphs. Then they will understand how to work with graphics and data and how to use unique wearable intelligent tools to provide research that will motivate students to research and present better usage for health care. Due to personal experiments, students will have more questions than in the as-is process due to higher motivation. Proceeding towards the final part of "As is" process classes will finish with investigation and discussion of the results.

The main features of the "To be" approach are time-saving and motivation increase. From a technical point of view, "To be" process is significantly more automatic. In this case, all methods of measuring and analyzing are provided by teachers and students. The entire analysis process – which includes sending measured data to a smartphone, saving data, processing data and creating a graph – must be conducted by the teacher or student. The data using additional software can be imported to Excel for further processing.

The "To be" process is more interactive, engaging, and beneficial for students. Furthermore, it motivates them to provide personal research and learn how to use individual smart gadgets in healthcare. "To be" process may save much more time when used effectively. Surely, it is worth noting that students are familiar with how to process the data during the "As is" process. Thus, it seems useful to combine these methods.

3.3 Methods for Integrating Personal Physiological Devices in STEM Education

3.3.1 Methods That Can Be Used in Biology

Topic: Measuring heart rate before and after physical activity with smartwatches/bands.

Learning objective: Develop knowledge and skills to use a smartwatch/band to measure heart rate and study the effects of physical activity on heart rate.

Target age group: middle and high schoolers.

Equipment: PPDs or smartwatch/bands or fitness tracks with heart rate monitoring functions; blood pressure, oxygen concentration (optional)

Experimental procedure: This method involves selecting 10 participants of each biological sex for the study. Firstly, each participant takes their heart rate, blood pressure (optional), and oxygen concentration (optional) measurements at rest. Afterwards, each student must do 20 squats. Following this exercise, he/she needs to take measurements one more

Table 1: Examples of devices of different companies, that can measure concrete parameters.

	Samsung	Xiaomi	Apple	Google	Other brands
Smart watches/bands					
Heart rate	100% of devises: Samsung Galaxy Watch 1, Samsung Galaxy Watch 2, Samsung Galaxy Watch 3	100% of devises: Amazfit T-Rex, Amazfit Bip S, Amazfit Stratos	100% of devises: Apple Watch Series 1, Apple Watch Series 2, Apple Watch Series 3	N/A	100% Aspolo SmartWatch U8, UWatch U8, SmartYou DZ09
Blood pressure	-(3,9%)Samsung Galaxy Watch 3	- (0%)	- (0%)	N/A	5.5% Havit HV-H1100, UWatch DT88 Pro, Aspolo DT88 Pro
ECG	(0 %)	+ (4.4 %) Xiaomi Mi Watch Color, Xiaomi Haylou Smart Watch	+ (52.5 %) Apple Watch Series 5, Apple Watch Series 6, Apple Watch SE	N/A	7 % No.1 DT28, Lige Smart, Gelius GP-L3
Oxygen content	- (3,9 %) Samsung Galaxy Watch 3	- (0 %)	10,2 % of devises: Apple Watch Series 6	N/A	11.7% Aspolo M1Plus, Aspolo DT35, UWatch E66
Sleep quality (stages of the sleep)	100% of devises: Samsung Smart Charm, Samsung Galaxy Fit E, Samsung Galaxy Watch Active	100% of devises: Xiaomi mi band 4, Xiaomi mi band 5, Amazfit GTS,	100% of devises: Apple Watch Series 5, Apple Watch Series 6, Apple Watch SE	N/A	100% Aspolo SmartWatch U8, UWatch U8, SmartYou DZ09
Smart scales					
Weight measuring	N/A	+ (100%) Xiaomi Mi Smart Scale 1, Xiaomi Mi Smart Scale 2	N/A	N/A	100% Laretti LR BS0015, HUAWEI Body Fat Scale, AEG PW 5653 BT Black
Muscle, fat, bone, and water content in the human body	N/A	+ (100%) Xiaomi Mi Smart Scale 1, Xiaomi Mi Smart Scale 2	N/A	N/A	100 % Yunmai Mini Smart Scale, Garmin Index Smart Scale, Acme Smart Scale

time. The analyzed data can be personalized as a graph on their smartphone and in a table drawn on a blackboard. The teacher finds regularities related to all students (including sex, weight, age, etc.) and explains them to the audience (figure 3) and fill the table 2.

Data analysis: We need to find regularities before and after physical activity to analyze the data. For example, compare actual and relative changes in indicators after physical activity in boys and girls, and we need to find dependencies from other indicators, such as height and weight.

Topic: The effect of sleep duration on heart rate.

Aim: Demonstrate to students that sleep duration affects the functioning of the circulatory system. Use the personal example to prove to students the importance of sleep and adherence to the daily habit

Equipment: Smartwatches/bands with heart rate, blood pressure (optional), oxygen concentration (optional), ECG (optional).

Experimental procedure: The research is personalized, so each student must carry it out separately. The method foresees changing the time regime in two steps. Firstly, students during the experiment must get sleep daily for seven days, falling asleep at 22:00 and getting up at 7:00. As soon as they wake up, students measure their heart rate, blood pressure (optional), oxygen concentration (optional), ECG (optional), as well as the quality of their sleep. After the first seven days of the test, students must fall asleep at 23:00 and wake up at 6:00 with students measuring the same parameters and recording the findings. To determine the cardiac cycle, use figure 4.

Data analysis: Analysis of the data is performed through comparison of the heart rate and oxygen concentration in the blood during the first stage (falling

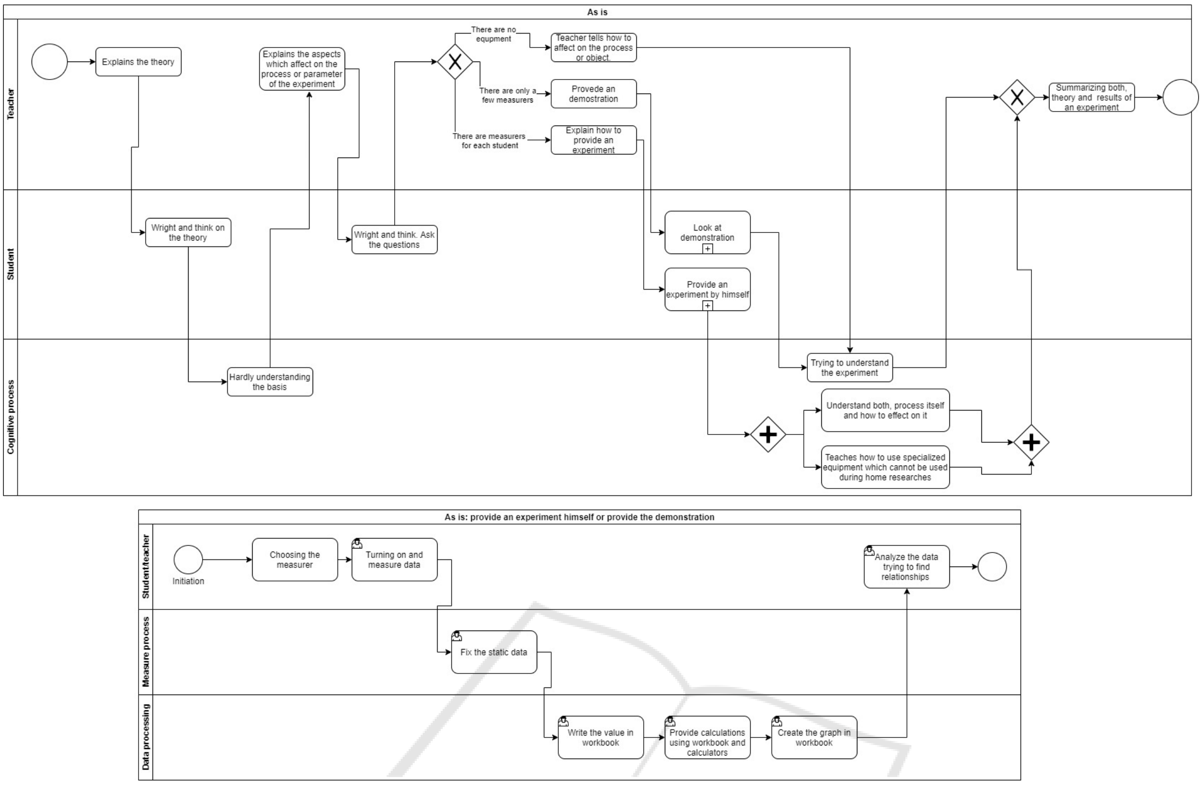


Figure 1: "As is" process (including technical interaction).

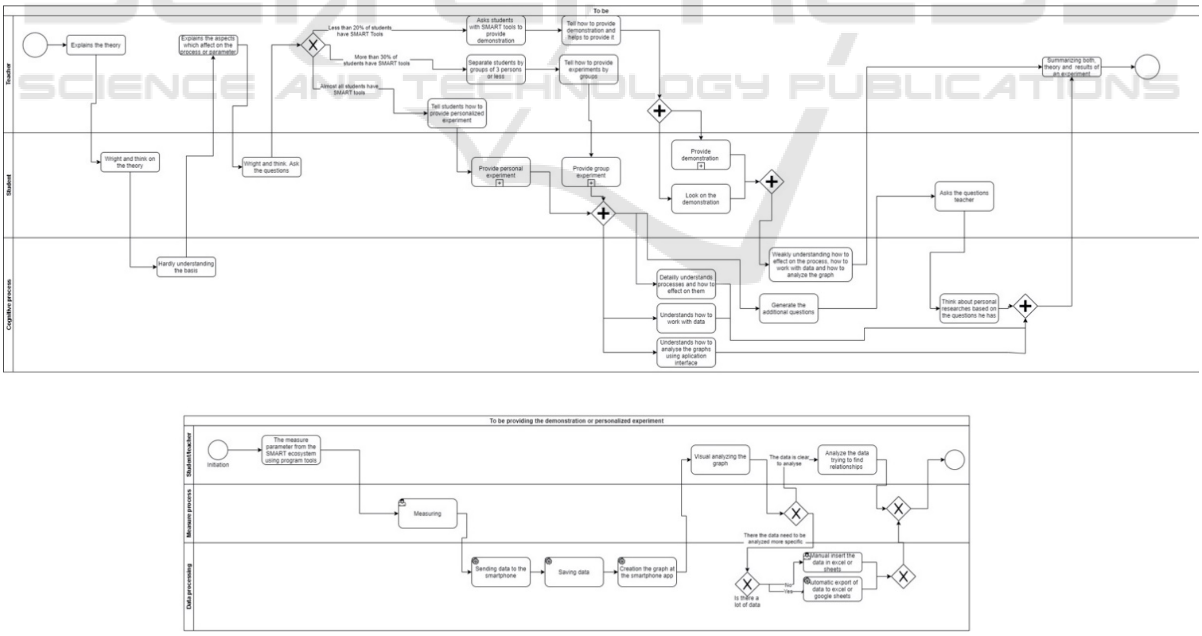


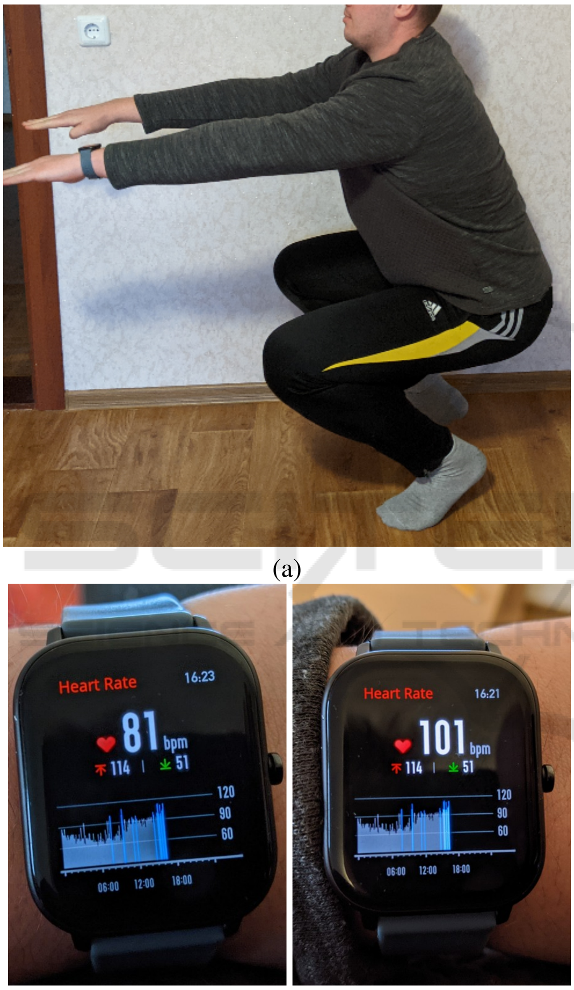
Figure 2: "To be" process (including technical interaction).

asleep at 22:00 and waking up at 7:00) and during the second stage (falling asleep at 23:00 and waking up at 6:00) with the normal condition. Using theoretical knowledge, changes in data must be attached to stress or adaptation state and fill the table 3.

The experiment is safe and can be conducted regardless of any health conditions. However, we recommend that the teacher or adults supervise the re-

Table 2: Table to experimental project “Measuring heart rate before and after physical activity with smartwatches/bands”.

Age	Sex	Heart rate (before)	Heart rate (after)	Blood pressure (optional) before	Blood pressure (optional) after	Oxygen concentration (optional) before	Oxygen concentration (optional) after



(a)

(b) (c)

Figure 3: Experimental part of the work (a), heart rate before (b) and after exercise (c).

search. Based on the results, it is possible to study adaptation, human comfort areas, and stress conditions. Figures to illustrate analysis process is shown in figure 5.

To determine the cardiac cycle, use figure 4.

Topic: Determination of differences in muscle, fat and bone composition in males and females.

Aim: Demonstrate to students some differences

Table 3: Table to project “The effect of sleep duration on heart rate”.

	Sleep duration	
	9 hours	7 hours
Heart rate		
Blood pressure (optional)		
Oxygen concentration (optional)		
The duration of the cardiac cycle on the ECG (*)		

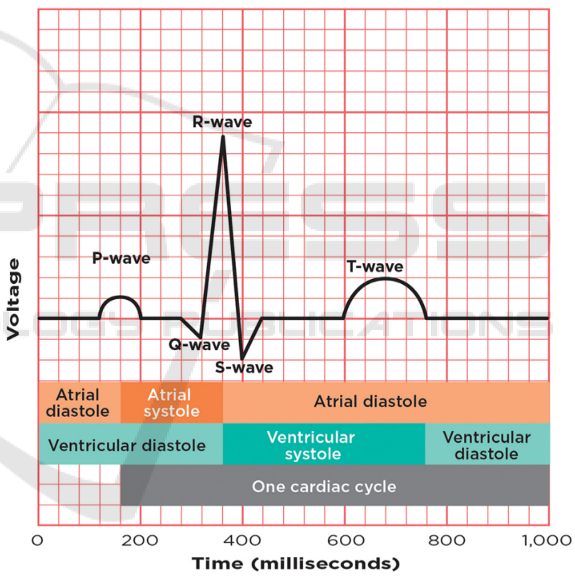
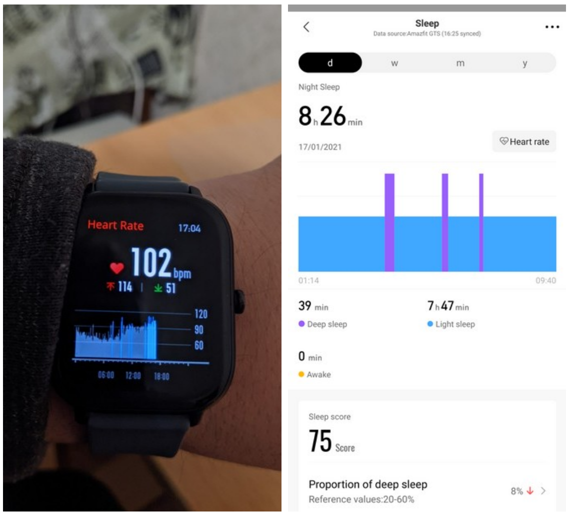


Figure 4: Relationship between ECG and cardiac cycle stages.

in male’s and female’s muscle, fat, and bone composition. Explain the reasons for such differences.

Experimental procedure: The technique involves selecting 10 participants of each sex for the study. Each of the students must measure muscle, fat and bone tissue. The analyzed data can be personalized as a graph on their smartphone and in a table drawn on a blackboard, where the teacher finds regularities and explains them to the audience and fill table 4.

Data analysis: To analyze the data, it is necessary to find regularities in the amount of muscle, fat, and bone tissue and compare the actual and relative speed



(a) (b)

Figure 5: Interface of smart watch's application sleep tab (Amazfit Zepp) (a) and the result of the analysis (b).

Table 4: Table to project "Demonstration to students some differences in male's and female's muscle, fat, and bone composition. Explain the reasons for such differences".

N	Age	Sex	The amount of muscle	The amount of fat	The amount of bone tissue

of change in male and female bodies. It is necessary to mention that the method is simple and easy to use in any school, especially, since it does not require sophisticated, expensive smart equipment. At the same time, it is useful because students measure the real indicator, compared to the traditional process, and they also learn to analyze data and graphs on their smartphones. Students are also more motivated to continue research after class. To analyze the data, we need to find regularities in the amount of muscle, fat, and bone tissue and compare the actual and relative speed of change in the amount of muscular, fat, and bone tissue in male and female bodies bodies (figure 6).

Topic: Determination of the oxygen saturation level in blood as indicator of SARS-CoV-2 (related to COVID-19).

Aim: Teach students to measure the level of blood saturation in the blood, which became especially relevant during the COVID-19 pandemic.

Equipment: PPDs or smartwatch or fitness trackers with the ability to monitor oxygen concentration – saturation.

(a) (b) (c) (d) (e)

Figure 6: The procedure of weight measuring (a), example of weight displaying (b), interface of integral automatic weight state assessment (c), details of body state (d, e).

Experimental procedure: Measure your oxygen concentration in blood with smartwatch/band. If the value is less than 95%, consult a doctor immediately and fill the table 5 (figure 7).

Table 5: Table to project "Determination of the oxygen saturation level in blood as indicator of SARS-CoV-2 (related to COVID-19)".

Condition	Blood saturation (oxygen concentration)
Before dinner	
After dinner	
Before exercises	
After exercises	

Data analysis: This experiment can be performed once and can be ported to Excel for a long time every day. For a healthy person, the level is the same and does not depend on any factor.

Figure 7: The result of oxygen content in blood determination.

3.3.2 Methods performed for a Long Time

Topic: Diet effect on body parameters, especially on the amount of muscle, fat and bone tissue.

Aim: Demonstrate to students the relationship between diet and the amount of body fat, to form an understanding of healthy nutrition.

Equipment: smart scales.

Experimental procedure: Firstly, students measure the amount of muscle tissue, fat tissue, and bone tissue using smart scales. Based on the results of measuring the amount of fat, muscle, and bone tissue in your body, students define a goal for themselves (for example, to get rid of fat tissue), consult with a teacher and, based on it, choose the diet. Students provide daily measurements of the amount of fat, muscle and bone tissue for six months, preferably in the morning before meals. The data can be analyzed using a smartphone or using an Excel table and to do it, fill table 6.

Table 6: Table to project “Diet effect on body parameters, especially on the amount of muscle, fat and bone tissue”.

N	Condition	The amount of muscle	The amount of fat	The amount of bone tissue
1	Before diet			
2	After diet			

Data analysis: Students must define the efficiency of the diet and make conclusions about the personal fit of the diet. Students must analyze the tendencies by determining the specific periods (stressed state of the organism and adaptation). The method can be used in any school, but it is a lengthy experiment. It is highly advised that such research is conducted under supervision of either a teacher or adults. It can be used as a source of data for research works aimed at participation in research contests among students.

Topic: The physical activity affects sleep duration and heart rate.

Aim: Demonstrate to students the physical activity effect on heart rate and sleep duration.

Equipment: Smartwatch or fitness trackers with heart rate monitoring functions; blood pressure, oxygen concentration (optional).

Experimental procedure: Measure the duration of sleep and heart rate, blood pressure, and oxygen concentration (optional) without physical effort before going to bed for a week. Afterwards, 3 hours before sleep, students must do one of the two possible things: A) Perform three sets, thirty squats each, and three sets with ten push-ups each; repeat the exercise cycle four times a week; spend three days resting. B) Perform a 2-4 km run each day for six days per week (1 day left to rest). Each day, students must measure the duration of sleep and heart rate, pressure, and blood oxygen level. Enter blood pressure, heart rate, and long and short sleeping phases into the table 7, and analyze the results.

Table 7: Table to project “The physical activity affects sleep duration and heart rate”.

N	Condition	Heart rate	Blood pressure	Blood oxygen level
1	Before activity			
2	After activity			

Data analysis: Compare the measured parameters before the activities and during the “active” week. Define whether the quality of the long phase of sleep is increased, define the changes in heart rate before sleep. Finally, compare the obtained data with well-being. The method is simple and can be used in almost every school, especially considering that only smartwatch/band is required. In addition, it can be used as a source for data fused in research works aimed at participation in research contests among students.

Topic: Physical activity effect on human muscle and fat tissue amount.

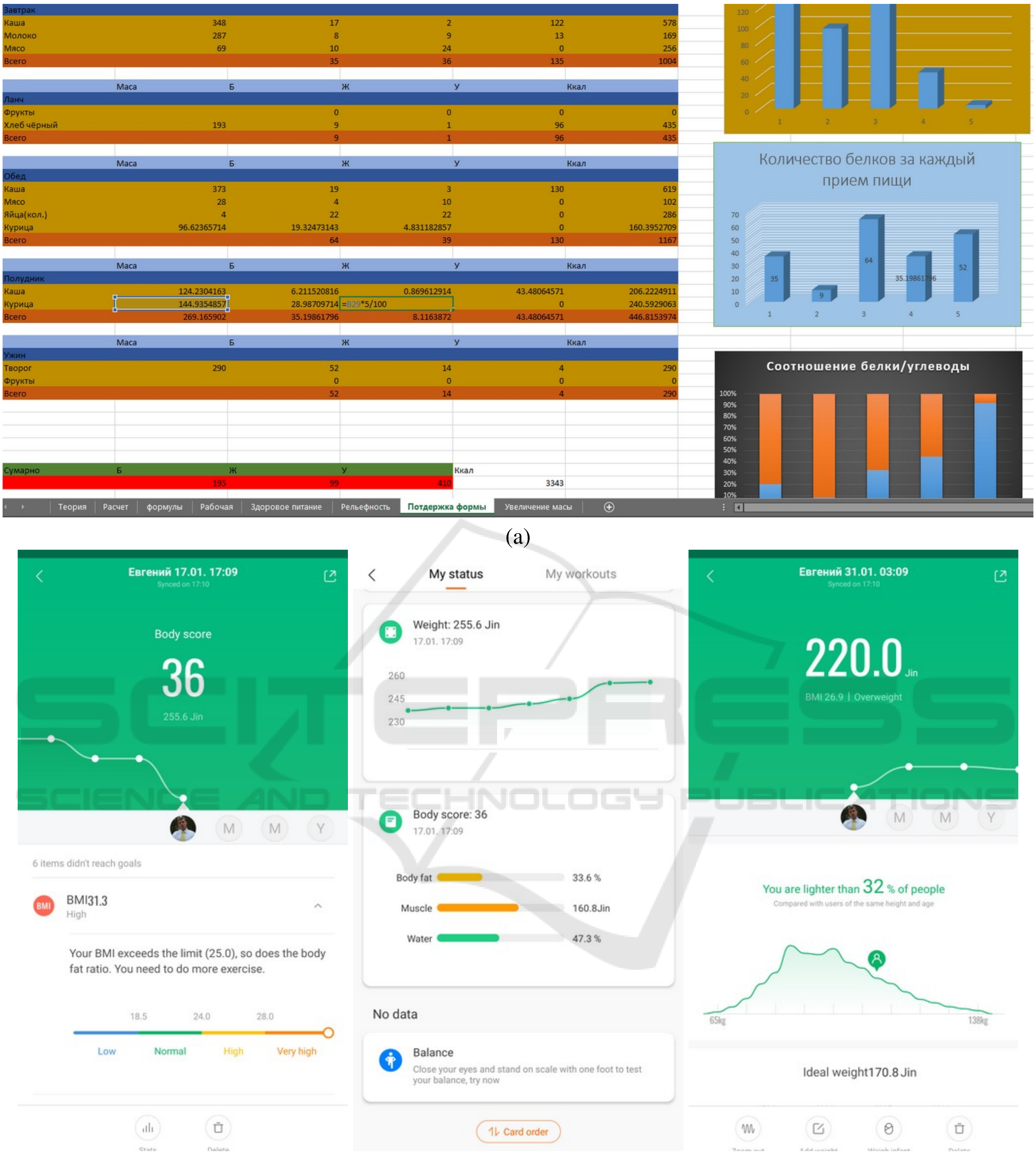
Aim: Demonstrate to students that regular exercise increases the amount of muscle tissue.

Equipment: smart scale.

Experimental procedure: Measure the amount of your muscle tissue using smart scales. Starting the next day, perform one of the two options:

A) Perform three sets, 30 squats each and three sets of push-ups, ten reps each. Repeat the exercise cycle four times a week. Leave three days for rest.

B) Make a 2-4 km run every day. Measure your muscle tissue using smart scales over six months. Measure the amount of your muscular tissue using



(a)

(b) (c) (d)

Figure 8: Screenshot of the method of mathematical modelling of student's nutrition ration (a), dynamic of the automatically body state estimation (b), current state of the body (fats, muscles, water content) (c) and weight dynamic and comparing with other users (d).

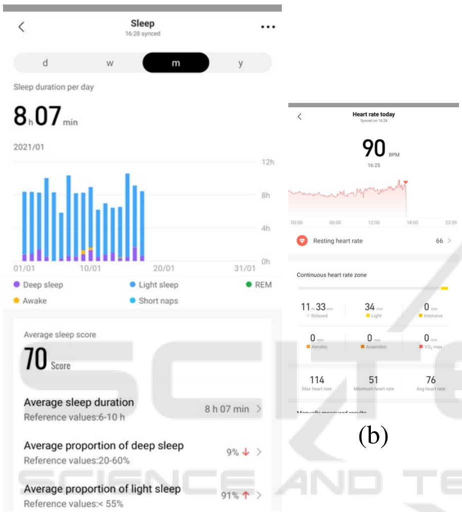
smart scales every day for six months. Capture data with the smartwatch/band interface as data or import it into Excel and, at the end of the year, analyze the data on your muscle tissue development and fill table 8.

Data analysis: Analyze the dynamic of the weight changes and their content. Define the tendencies in changes of fat and muscles tissue amount. Define changes in time stages (stress and adaptation). Calculate the weight of fat and muscles lost during the

Table 8: Table to project "Demonstrate to students that regular exercise increases the amount of muscle tissue".

N	Condition	The amount of muscle	The amount of fat	The amount of bone tissue
1	Before exercises			
2	After exercises			

research. Try to define whether the process of fat decrease is linear, or features steps. Describe the steps, if applicable. The method involves performing exercises, which can be qualified as doing sports, so a preliminary medical examination and teacher's supervision are required.



(a) (b)

Figure 9: Dynamic of the long and short stages of sleep (a) and dynamic of the heart rate (b).

Topic: Influence of fitness zone training on resting heart rate.

Aim: To teach students to individually calculate the maximum heart rate and the number of contractions that correspond to the fitness zone of physical activity, to select a set of exercises, the implementation of which will determine the required heart rate.

Equipment: PPDs or smartwatch/band or fitness trackers with heart rate monitoring functions.

Experimental procedure: Students measure heart rate with a smartwatch/band. For the next step, they calculate maximum heart rate according to the formula:

- For females $209-(0.9 \cdot \text{age})$
- For males $214-(0.8 \cdot \text{age})$

Then count 70-80% of maximum heart rate. This will be the optimal amount of heart rate during exercise. Students need to choose their own exercises, which will require the number of heartbeats controlled by a smartwatch/band. After three months of regular exercise, students measure their resting heart rate again.

Data analysis: Define the optimal physical activity that provides a student's heart rate in the fitness zone. Define the mean physical activity in the group and compare the individual results. Define dependencies of optimal physical activity on sex, weight and age.

Students learn to use smartwatches/bands and process their data when doing work.

Topic: Effect of holding breath on heart contraction.

Aim: investigate whether holding one's breath affects heart rate and ECG.

Equipment: Smartwatches/bands with heart rate, blood pressure (optional), oxygen concentration (optional), ECG (optional), stopwatch.

Experimental procedure: It is first necessary to measure the time of maximum possible period of holding breath in the standing and sitting position after inhalation/exhalation with a stopwatch. Between measurements, it is necessary to have a rest for no less than 5 minutes. Next, a student needs to hold his/her breath and measure one of the following parameters: heart rate, blood pressure (optional), oxygen concentration (optional), and ECG (optional) while standing. Rest for 5 minutes is due next. A similar experiment has to be repeated in a standing position.

Data analysis: Analyze the time of holding breath among different students. Does this value depend on inhalation/exhalation, body position, sex, and level of physical fitness? Fill in table 9 (A). Compare heart rate, blood pressure (optional), oxygen concentration (optional), duration of the cardiac cycle on the ECG without holding breath and with respiratory arrest during exhalation/inhalation in sitting and standing positions. Fill in table 10 (B).

Table 9: Table A to project "Effect of holding breath on heart contraction".

N	Condition (sex)	Respiratory arrest time after inhalation (c)	Respiratory arrest time after exhalation (c)
	Sitting position (female)		
	Sitting position (male)		
	Standing position (female)		
	Standing position (male)		

Table 10: Table B to project “Effect of holding breath on heart contraction”.

N	Condition	Heart rate	Blood pressure (optional)	Oxygen concentration (optional)	Duration of the cardiac cycle (optional)
	With respiration, in a sitting position				
	With respiration, in a standing position				
	Breath held after inhalation, sitting position				
	Breath held after inhalation, standing position				
	Breath held after exhalation, sitting position				
	Breath held after exhalation, sitting position standing position				

Topic: Influence of controlled hyperventilation on the duration of holding breath.

Aim: Demonstrate to students that the removal of CO2 from the body affects the breath-holding time.

Equipment: Smartwatches/bands with a stopwatch.

Experimental procedure: A student has to hold one's breath for as long as possible, record the duration of this state. The next step presupposes assuming horizontal body position. A student has to take 30 intense breaths (breathe a little faster than usual) then exhale calmly and relax their lungs. Afterwards, oneneeds to move a little quicker than usual and then hold breath on exhaling as long as possible. It is necessary to record the duration of the breathless state. A student is to takeone deep breath next and hold you're their breath for 15 seconds and repeat the actions described above two more times. This technique should not be used while swimming, driving, in the shower, or anywhere else while standing and fill table 11.

Table 11: Table to project “Influence of controlled hyperventilation on the duration of holding breath”.

N	Condition	Duration, seconds
1	Simple approach to holding breath	
2	Holding breath with hyperventilation, first time	
3	Holding breath with hyperventilation, second time	
4	Holding breath with hyperventilation, third time	

Data analysis: Compare the duration of holding breath without and with controlled hyperventilation. How does preliminary controlled hyperventilation affect the breath-holding time? What is the impact of each iteration?

Topic: Effect of hypoxia on blood oxygen levels.

Aim: Demonstrate to students that the concentration of oxygen in the blood can be temporarily affected.

Equipment: Smartwatches/bands with oxygen concentration.

Experimental procedure: Hold your breath for as long as possible. At the end of the period without breath, use the gadget's oximeter function to measure the value of oxygen concentration in the blood. Assume a horizontal body position. Take 30 deep breaths (breathe a little faster than usual). Exhale calmly, just to relax your lungs. It would be best if you breathe a bit faster than normal. Hold your breath on exhalation as long as possible. At the end of the period without breath, use the gadget's oximeter function to measure the value of oxygen concentration in the blood. Take one deep breath and hold it for 15 seconds. Repeat these steps two more times. This technique should not be used while swimming, driving, in the shower, or anywhere else while standing and fill table 12.

Table 12: Table to project “Effect of hypoxia on blood oxygen levels”.

N	Condition	Oxygen concentration, %
1	Before holding breath	
2	Simple approach to holding breath	
3	Holding breath with hyperventilation, first time	
4	Holding breath with hyperventilation, second time	
5	Holding breath with hyperventilation, third time	

Data analysis: Is it possible to reduce the oxygen concentration in the blood by simply holding your breath? Compare the value of blood oxygen concentration due to respiratory arrest with and without controlled hyperventilation. How does preliminary hyperventilation affect blood oxygen levels? What is the impact of iteration?

Topic: Effect of vagus nerve stimulation on heart rate.

Aim: Demonstrate to students that vagus nerve stimulation can affect heart rate.

Equipment: Smartwatches/bands with heart rate.

Experimental procedure: Measure your heart rate. Wash your face with cold water or immerse it in a bowl of cold water for a few seconds. Measure the heart rate again.

Data analysis: Compare heart rate before and after face contact with cold water. What is the influence of vagus nerve stimulation on heart rate? Can this effect be applied in practice?

Table 13: Table to project “Effect of vagus nerve stimulation on heart rate”.

N	Condition	Heart rate, bpm %
1	Before nerve stimulation	
2	After nerve stimulation	

Topic: Does the heart rate change depending on the position of the human body?

Aim: Demonstrate whether the heart rate changes with the different position of the human body?

Equipment: Smartwatches/bands with heart rate.

Experimental procedure: Lie down horizontally. Wait a few minutes. Measure your heart rate. Sit up. Wait a few minutes. Measure your heart rate. Stand up. Wait a few minutes. Measure your heart rate.

Data analysis: Compare the heart rate at different body positions. Is there a difference? How can this be explained?

Table 14: Table to project “Does the heart rate change depending on the position of the human body?”.

N	Condition	Heart rate, bpm %
1	Lying	
2	Sitting	
3	Standing	

4 DISCUSSION

4.1 Advantages of Using PPDs in the Educational Process

The main functions of PPDs devices in the educational process are defined as:

- *The training functions.* The training involves direct use of PPDs to study individual subjects, primarily STEM subjects. Most often, certain types of devices are used as a tool to perform a learning task. They can also be used in the design of research activities and the performance of research tasks.
- *The health-preserving function* involves using PPDs devices as a tool for monitoring the prime indicators of the body in order to form a healthy lifestyle with the subsequent formation of skills to control physical shape. It can also monitor vital signs for people in need of such service.
- *The control function* involves using devices as a tool for self-control and external control (parents, managers). We control certain activities and the children’s GPS, especially among primary school and preschool children, by parents or other people performing parenting duties. If necessary, such control may be carried out by a teacher. It helps to increase self-control, which is supported by habits.
- *The ergonomic function* involves using devices to improve productivity, namely planning, coordinating the use of their time, and the effectiveness of the actual use of tools that help increase the productivity of each child and the educational process as a whole.

Rational use of PPDs devices and time allows the control the child’s admissible physical, nervous and mental loads while also having the potential to increase said child’s working capacity.

The use of smartwatches/bands in the learning process contributes to the development of principal competencies:

- *Mathematical competence* expressed in the formulation of navigation, calculation of the necessary parameters using indicators created at a reasonable age.
- *Competencies in the field of natural sciences, engineering and technology* are formed based on acquiring skills in working with physical parameters, vital signs, geolocation data, ability to work with different models of specific devices and their analogues, etc.; innovation is defined in the formation of skills in the use of leading technologies for personal and public health. During the connection process of smartwatches/bands with a smartphone, the students get acquainted with the concepts of “cloud technology”, “synchronization”, and “remote access”. The mastery of this knowledge will facilitate information and digital competence formation.
- *Social competencies* manifest in the configuration of the ability to be aware of personal feelings and pay attention to internal needs, which

is displayed in the perceived need to maintain a healthy lifestyle. Smartwatches/bands encourage students to take accurate measurements of their heart rate, blood oxygen concentration and stress levels. This knowledge allows them to produce health-preserving competencies. For example, a student can see that negative emotions (anger, aggression) accelerate their heart rate on their smart clock. In addition, these devices can contribute to the motivation increase to maintain a healthy lifestyle. For instance, one can offer students a cup of coffee, an 'energy drink' and then measure their heart rate. Such experiments will demonstrate the effect of certain substances on the functioning of individual organs and systems.

Smartwatches/bands also have considerable potential to develop valuable skills and habits. For example, most of these devices have a reminder mode. At first, one can set up a notifier that one needs to do some exercises after 40 minutes in a sitting position (while doing homework). After 40 repetitions of this sequence, a helpful skill becomes a habit that can be reproduced without a smart device.

Notwithstanding, smartwatches/bands have the most pedagogical potential in shaping research competencies.

The document "The European Qualifications Framework for Lifelong Learning" (Guest, 2007) determines that a high-level specialist should have research competence in their field of knowledge. Research competence is the ability of the acquired education to perform educational research tasks and carry out research activities to obtain new knowledge and find ways to apply them, following the profile of the study (Nechypurenko and Soloviev, 2018; Cabinet of Ministries of Ukraine, 2020).

With the help of smart watches/bands, a student can obtain a large amount of data – this is the stage of acquiring new knowledge. A student can also analyze this data with mathematical tables – thus fulfilling the step of creating a knowledge system.

It is also possible to use smartwatches/bands to create motivation for learning activities within the STEM approach. For example, students observe the phenomenon of heartbeat acceleration after physical activity, and they will ask problematic questions: Why does it happen? How is the heart activity regulated? Therefore, the whole lesson is laid out around these questions of doubt.

There is also potential in using smartwatches/bands for students with special needs. For example, it is challenging to teach a child with hearing disabilities how to measure their pulse. Smartwatches/bands can help solve this issue.

This article presents several methods of using smartwatches/bands during the learning process. These methods can be divided according to the time they consume:

1) methods that can be directly used in the learning process at school;
2) methods that ensure long-term experiments, for example, within 24 hours, the latter's application is relevant to the performance of research work or projects by students;
3) methods that can be used out of school and after school.

Thus, the use of the smartwatch/band allows:

1) to create motivation for learning activities;
2) to create an impulse for a healthy lifestyle;
3) to develop information-digital, health care and research competencies.

4.2 Alignment of PPD Use with Curriculum Standards

IoT technologies and Cloud Services are becoming more and more popular in education (Fossland and Krogstie, 2016). IoT will significantly improve the quality of education. Implementation of IoT in education will create new ways to learn by supporting more personalized and dynamic learning experiences. IoT will give teachers new methods to explain the material during lessons (Fossland and Krogstie, 2016; Mendling and Weidlich, 2013). Moreover, IoT will offer an excellent opportunity to provide individual lessons to people with some disabilities (Morais et al., 2020). However it is lack of the studies related to using them in education. Furthermore, it was shown that the use of IoT technologies in the educational process will improve the quality of learning (Wiechetek et al., 2017). Besides, their scientific research showed that the use of IoT technologies significantly increases overall opportunities to fulfill creative abilities for both teachers and students.

Using the Internet of Things in Education is excellent for involving and educating students. Different researchers in their articles have tried implementing PPDs to provide various services in smart campuses accessible on handheld devices by ensuring ideal connectivity among multiple things. Some authors create educational systems based on wearable devices and IoT technologies (McRae et al., 2018; Abd-Ali et al., 2020). This education system integrates with the IoT tools and special apps to create more interactions between teachers and students in class while providing more innovative learning possibilities. Also, IoT can inspire school students and increase their concentration in the classroom during the lessons (Liang et al., 2019).

Previously, it was proposed to use such technologies as mobile Internet devices to form the general scientific component of a bachelor in electromechanics competency in the modelling of technical objects (Modlo et al., 2019a,b). However, using mobile Internet devices is a perspective way to improve the quality of education in general. The authors have proposed different tools to work with. For example, mobile augmented reality tools, mobile computer mathematical systems, cloud-oriented tabular processors as modelling tools, mobile communication tools for organizing joint modelling activities and more (Mavroudi et al., 2018; Pervez et al., 2018).

At the same time, despite showing promise PPDs are not widely used in education. There is currently no complete, systematic list of approaches and guidelines for integrating PPDs in the classrooms. Today, the most popular PPDs is a smartphone, but there is a lack of methods that have been proposed methods implying the use of smart scales and bands/watches. PPDs are becoming increasingly popular in most of the healthcare system. For example, some human diseases require constant monitoring of the heart. Devices used for this purpose transmit data to the cloud and, if necessary, signal their users regarding any issues, requiring immediate attention (Modlo et al., 2019b). PPDs have been used widely in everyday life, sport, medicine and healthcare (Wu et al., 2008). For example, wearable devices are used to monitor the state of the patients in clinics and to alert the doctors whenever necessary (Wu et al., 2008). However, there is a lack of studies that substantiated using of PPDs.

One of the proposed systems were collected data from the classroom, not only presenting information to students but also collecting data based on their interactions. This data can be uploaded and accessed by using a smart e-learning application. In smart classrooms, tools are aimed at either real-time monitoring of teaching space or PPDs that support students, when multiple functions are brought together (Modlo et al., 2019a; Stradolini et al., 2017; Veeramanickam and Mohanapriya, 2016).

Some schools, colleges and universities, such as Oral Roberts University in Oklahoma, have introduced the mandatory wearing of fitness bracelets to monitor students' physical activity during the day or physical training. However, there are also potential concerns about the consistent use of PPDs. For example, psychologists warn that wearing these devices can harm people with digestive disorders (Valks et al., 2019). Buchanan (Buchanan, 2015) also proves the positive role of fitness bracelets for students' health, as they create motivation to take the required number of steps per day. A study by Ertzberger and Martin (Ertzberger and Martin, 2016) showed that teachers wear fitness bracelets to increase motivation for physical activity).

4.3 Role of Personalized PPDs in Educational Standards of Ukraine

The introduction of STEM in Ukraine is regulated at the legislative level in the Concept of Development of Natural and Mathematical Education (STEM). According to this document, science and mathematics education (STEM) is a holistic system of science and mathematics education. The term 'interdisciplinary' in STEM according to Ukrainian interpretation means the integration of natural sciences (biology, chemistry, etc.), but not such disciplines as science, technology, engineering and math (Polikhun et al., 2018). Usually, in English-language sources, integration is understood as the relationship of one of the disciplines of sciences (biology, chemistry, or physics) with engineering and mathematics to solve a particular problem. According to the concept, the goal of STEM education is the development of personality through the formation of competencies, natural science picture of the world, worldviews, and life values using a transdisciplinary approach to learning. In our opinion, it is difficult to apply a transdisciplinary approach during the real process of learning at school. Transdisciplinary implies deep integration of disciplines in content and methods and foresees providing a new quality of research or problem-solving. Transdisciplinary provides close integration of knowledge fields, and – as a result – disciplines such as nanotechnology emerge. Due to the conditions of the modern Ukrainian school education system, such courses are practically not conducted. So, the term transdisciplinary will not be used in this paper.

In the Ukrainian Concept, STEM, natural sciences and mathematics are relegated to a single document. We believe that the concept quite successfully describes the aims of STEM education, including the formation of skills to solve complex, practical problems, comprehensive development of personality by identifying its inclinations and abilities; mastering the means of cognitive and practical activities; education of a person who strives for lifelong learning, the formation of practical skills, and creative application knowledge.

Thus, considering the Concept of natural-mathematical education (STEM) in Ukraine, the use of personal PPDs during the educational process is not only modern but may also be effective and promising.

Providing educational research with students using PPDs corresponds to STEM. Since biology is one of the scientific disciplines, it is corresponding to sciences (S). Furthermore, the teacher may ask questions and request students to find and analyze some scientific publications to formulate hypotheses. In addition, students provide the research using proposed methods. As a result of each work, students may make conclusions that are related to their optimum to reach some aim. For example, they may find their optimum that keeps their health and well-being during physical activities, which in turn leads to the formation of personalized methodology (technology; T) in personal health. Taking part in classes, students will think or ask about how a PPDs works: how it measures, how it provides calculation, and how it sends data on the devices. Thereby, it will develop their engineering thinking (E). Proposed methods contain all automated calculations by PPDs manual calculations by students, and analysis of obtained results (M).

Nevertheless, despite some deviations from the classical (American) interpretations of definitions related to STEM education in Ukraine, in our opinion, the Concept positively impacts the development of education and pedagogy in Ukraine and ensures using enchasing motivation and measuring tools such as PPDs.

4.4 Alignment with Relevant K-12 STEM Education Standards in the United States

The activities and methods for implementing PPDs in STEM education align well with a number of STEM education standards in the United States. For example, Next Generation Science Standards a relevant standard for students in elementary grades 4-PS4-3 Waves and Their Applications in technologies for Information Transfer (Next Generation Science, 2023). This standard supports teachers and students in generating and comparing multiple solutions that use patterns to transfer information (e.g., ECG information sent from a smartwatch to a mobile phone smartphone interface).

Similarly, the Common Core State Standards for teaching literacy and mathematics include a set of standards for measurement and data analysis. For instance, standard CSS.Math.Content.5.MD.B.2 requires that students learn to represent and interpret data such as plotting the trends in a person's ECG based on smartwatch recordings (Common Core, 2011).

Finally, a highly relevant set of US standards to support the use of PPDs in STEM education was developed in 2016 by the International Society for Technology in Education (International Society for Technology in Education (ISTE), 2023). For example, students are expected to "critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts and make meaningful learning experiences for themselves and others" (1.3 Knowledge Constructor). Students are also supposed to engage in computational thinking to "develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions" (1.5 Computational Thinker). All these standards are highly relevant to the implementation of PPDs in STEM education and support teachers' use of smart technologies in the classroom.

Thus, the use of PPDs meets Ukrainian and American educational standards. The development of methods for using PPDs during the educational process is an urgent issue.

5 CONCLUSIONS

The number of PPDs increases due to their usability and usage potential. In 2022, up to 1.1 billion individual smart instruments may be represented due to the shift from 4G to 5G communication protocols, meaning that every seventh person on the Earth will use PPDs. The article showcases exact methods used during educational research of STEM-based processes.

The "As is – To be" BPMN method was proposed to evaluate the effect of the proposed method. Using these methods proved that using smart personal tools during STSTEM education characterized by enhanced automatization provides development of student's thought process, use of graphs, calculation and encourages students to conduct their own individual researches.

Training, health-preservation, mathematical competencies, competencies in the natural sciences, engineering and technology, and social competence can be achieved using personal physiological tools to provide educational research.

The following methods have been developed and are ready to use – "Measure of the heart rate before and after physical activity with smartwatches/bands", "Effect of sleep duration on heart rate", "Determination of differences in muscle, fat and bone composition in males and females", "Determination of the level of saturation in suspected COVID-19", "Diet effect on body parameters, especially on the amount of muscle, fat and bone tissue", "The physical activity effect on sleep duration and heart rate", "Physical activity effect of human muscle and fat tissue amount", "Influence of fitness zone training on resting heart rate".

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