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Article

Biosensors on teaching quality in applied higher education institutions from a biomechanical perspective

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Abstract: This study examines the impact of wearable biosensor technology on student engagement and academic performance in educational settings. The purpose was to investigate how experience with biosensors influences engagement levels and whether this engagement correlates with academic success. Key issues addressed include the unexpected negative correlation between biosensor experience and academic performance, indicating that reliance on technology may not always enhance learning outcomes. Innovative aspects of this research involve identifying the complex relationship between technology use and educational effectiveness, underscoring the need for strategic integration. Proposed solutions include enhanced educator training and active learning strategies that effectively utilize biosensors. The feasibility of these solutions is supported by existing literature on effective teaching practices. Ultimately, findings highlight the importance of thoughtful technology integration to foster meaningful learning experiences.

Keywords: wearable biosensors; student engagement; academic performance; educational technology; active learning

1. Introduction

1.1. Background on biosensors and teaching quality

Biosensors are of high complexity, capable of identifying transformations in bio parameters, and can translate the changes to measurable signals in health, environment, and academia [1]. In educational environments, biosensors can improve students' physiological parameters like heart rate, stress level, or cognitive load, which is valuable feedback and useful for improving teaching and learning processes (indicated in **Figure 1**). Their utilization is significant in the context of applied higher education institutions, as the methods developed enable the differentiation of the individual learning approaches for each learner. For instance, by measuring physiological variables, teachers can discover that learners are stressed during sessions. This data allows for the instructors to teach their students more flexibly.

The teaching quality affects student satisfaction, retention, and achievement. Teaching quality assumes a higher degree of significance in applied higher education institutions as this aim to develop both practical experience and theoretical background. Incorporating biosensors helps transition from traditional teaching practices and applying modern teaching [2]. For instance, by wearing such sensors, students' stress during examinations or practical can be sensed, and the instructors can assist appropriately (process shown on **Figure 2**). Integrated use of biosensors in learning institutions helps the concerned institution to provide an individualized learning environment that meets students' needs.

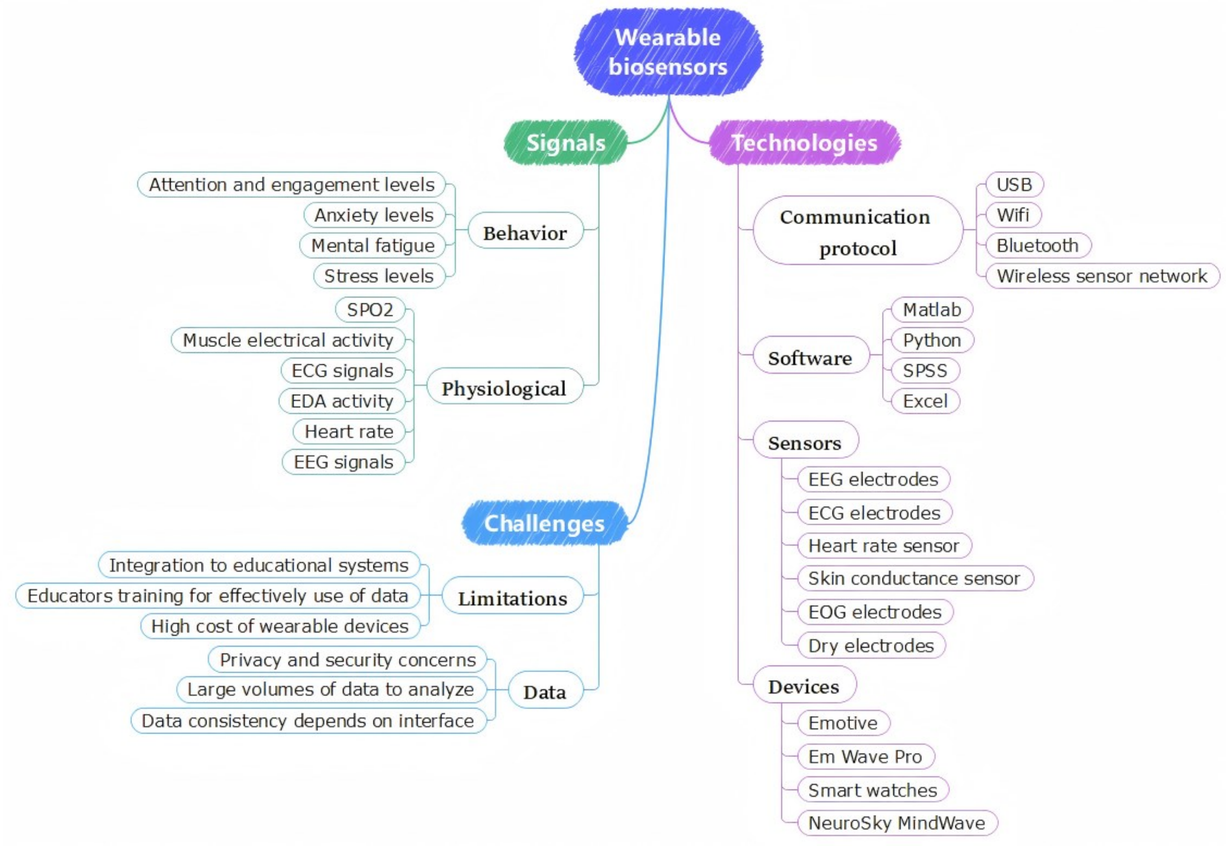

Figure 1. The application and challenges of wearable biosensor technology.

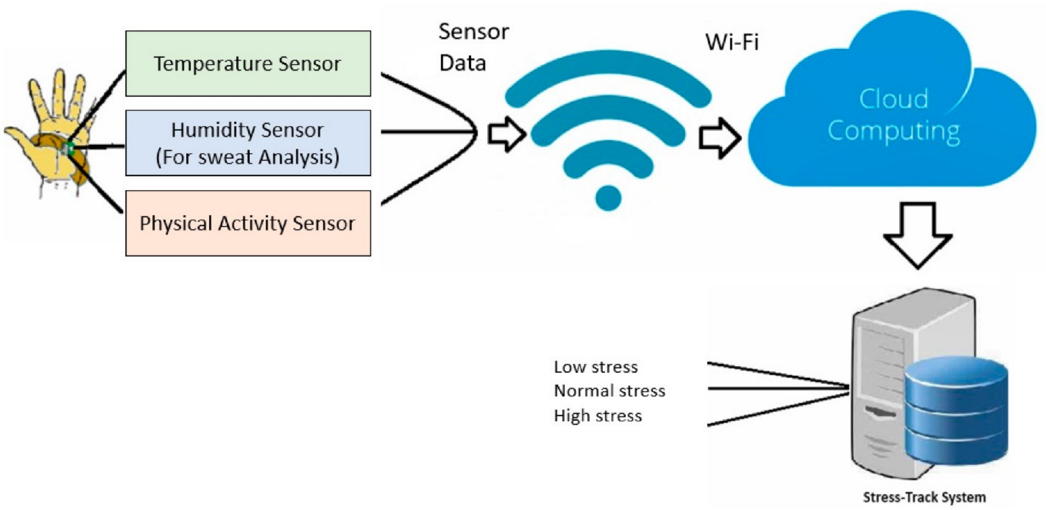

Figure 2. Stress monitoring using machine learning, IoT, and biosensor technology.

Further, incorporating biosensors into practice also connects with the recent trends in educational practices that include active learning and learner-centered paradigms. Relative to the current student's internal states, biosensors allow educators to teach in a way that is more sensitive to students' learning styles [3]. The transition from the traditional structural delivery of course content to a personalized system that can foster better learning and higher customer satisfaction. Moreover, biosensors can contribute to creating new learning activities based on physical activity and movements. For example, using biosensors and interactive technologies may foster active learning and information acquisition.

From a biomechanical perspective, it is crucial to understand how physical factors affect the quality of teaching in order to improve the educational process. Analyzing the mechanical attributes of organisms, or biomechanics, offers educators and students relevant information concerning posture, movement proficiency, and ergonomics as applied in the classroom [4]. Good posture is important to avoid soreness, especially for teachers who are either presenting material or modeling an exercise for most of the day. Through these biomechanical factors and the application of biosensors to deliver technological solutions, institutions can help alleviate unhealthy demeanor and contribute towards improved productivity within an educational environment.

Using biomechanical angles, biosensors improve teaching effectiveness from the methodological viewpoint, and despite several implementations in kinesiology, this area has not found essential empirical support in connection with applied higher education institutions (shown in **Figure 3**). The main research issue investigated in the present work is the absence of sound knowledge regarding the practical application of biosensors to enhance pedagogical practices and the biomechanical aspects of educators and learners.

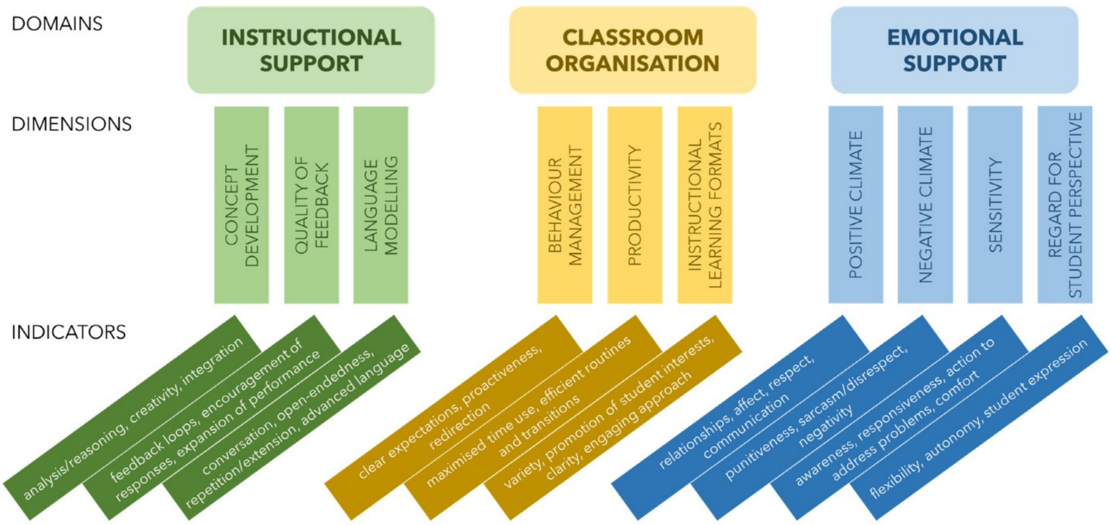

Figure 3. The teaching through interactions framework.

1.2. Research question and objectives

The objectives of this study are as follows:

RO1: To examine how biosensors influence teaching methods and overall effectiveness.

RO2: To explore the role of biomechanical factors in shaping teaching quality.

RO3: To assess student engagement levels associated with biosensor usage in educational settings.

The primary research question guiding this study is: How do biosensors impact teaching quality and student engagement in applied higher education institutions from a biomechanical perspective?

1.3. Scope and limitations

This research centers on the applied higher education campuses already adopting biosensor technology in their learning activities to improve the teaching quality biomechanically. The analysis of the different biosensors applied in learning environments includes wearables that measure physiological states and their integration across higher learning disciplines. Thus, by focusing on these particular contexts, the research intends to describe how biosensors can enhance teaching and learning outcomes. Nevertheless, several limitations need to be recognized within this study. Selecting the participants may lead to some bias that could limit the transfer of results across different contexts of education.

2. Materials and methods

2.1. Research design

This research work adopted a quantitative research method to examine the effect of biosensors on teaching effectiveness and students' participation in applied higher education settings. The quantitative approach was most appropriate in this study since it involved collecting numerical data that could be analyzed statistically with a view to establishing patterns or relationships between variables or comparing one variable with another. This called for the collection of quantitative data concerning the participants' impressions of the practical use of biosensors in the promotion of teaching exercises by using specifically formulated tools in the form of questionnaires or surveys.

The quantitative approach also enhanced the ability to generalize results across a larger population, which provided useful recommendations that might assist institutions in enhancing educational quality by integrating technology into their curricula. Moreover, those correlations involved the variables being synonymous with each other; for example, biosensor use was related to students' level of engagement. It also proved efficient since data were collected simultaneously in a cross-sectional research design that addressed participants' perceptions and experiences.

2.2. Participant selection

The participants for this study were chosen following some criteria from many higher education institutions that are applying biosensor technology. Respondents comprised teachers and learners enrolled in programs that use biosensors in their academics. Specific criteria for participation included: Key participants needed to have prior working knowledge of biosensor applications in an educational environment; hence, selectivity was important. Participants were recruited based on their connection to courses taught with biosensors and learning activities incorporating biosensors. The participants were between 18–45 years with a fair distribution of frequency between male and female.

2.3. Data collection methods

Participants' views of biosensors in teaching were obtained through structured questionnaires. The survey tool used closed questions, which are measurable. This approach helped enrich client data while staying more consistent in quantitative analysis. The rationale for choosing surveys is rooted in the fact that a relatively large number of participants can be reached, and the received data may be statistically analyzed. The structured questionnaires were distributed through online to ensure easy accessibility and participation.

These points included satisfaction of the biosensors in enhancing the quality of teaching, perceived levels of engagement during learning experiences, and biomechanical concerns observed by participants. Some were Likert-scale questions stating the level of respondent's agreement on the effectiveness of biosensors. The survey instrument was pre-tested on a sample of respondents to ascertain a clear comprehension and applicability of the survey questions before extending it to the required population. Results from this pilot phase informed the fine-tuning of the survey items for clarity and relevance to the included items.

2.4. Data analysis techniques

Structured questionnaires were also used in sample data analysis, and the software used is the Statistical Package for the Social Sciences (SPSS), which is well known for its efficiency in quantitative data analysis. To compare means between two groups (educators and students), Analysis of Variance (ANOVA) and correlation analysis were used, and regression analysis was used to comprehend relationships between the usage of biosensors and student engagement levels.

These techniques revealed how biosensors affected teaching quality and acknowledged variations influenced by demography or the learning environment. Also, percentage averages were used to present demographic information about the participants and the average response pattern of the participants to the questions. Using these statistical methods, this study sought to provide an all-round analysis of how biosensor technology impacted teaching practices within all the applied higher learning institutions.

2.5. Ethical considerations

The ethics of research involving human subjects are highly sensitive. Permission to conduct research among the participants was sought, and approvals to conduct research involving humans were obtained from relevant institutional review boards or ethics committees before data was collected from the participants. To obtain informed consent, participants read and signed explanations detailing the aim of the study. These actions would be taken regarding them and possible complications and advantages involved in the study. The consent process ensured that participants appreciated their rights, such as their right to withdraw from the study without any repercussions.

Further, steps were taken to safeguard respondent anonymity by quantifying responses using codes instead of names and preserving data in password-restricted files retrievable only by researchers. The data reporting involved reporting out of pooled outcomes while maintaining the anonymity of different subjects in the study.

To achieve this, the study followed relevant ethical standards to safeguard the participants and ensure the result's credibility.

3. Impact of biosensors on teaching effectiveness

Educational settings that employ biosensors have shown immense possibility to improve teaching efficiency and engagement. Wearable biosensor technology (WBT) has been established as an advanced method of delivering education through real-time learning that may be used to adapt teaching methodologies to different settings. Thus, learners' learning states, including emotional and cognitive states, can be captured through biometric sensors such as heart rate variability and galvanic Skin Response, indicating that educators can collect the following biometric data during lessons: heart rate variability and galvanic skin response (main wearables are shown in **Figure 4**) [4]. This capability makes it easy to change strategies used in class to teach depending on the student's level of participation and stress levels to improve the learning process. Incorporating biosensors will enhance learning outcomes because of the flexibility inherent in one-on-one instruction. In addition, observing cognitive, emotional, and physical data in real-time also helps educators to see when the learners might be having difficulties or even bored, hence being able to attend to them in the right way to aid their learning process [5].

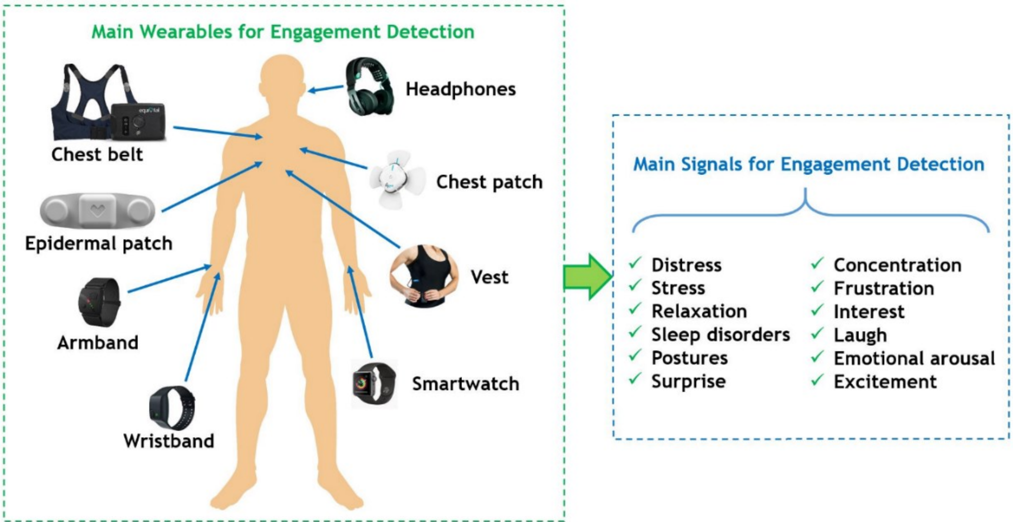

Figure 4. Main wearables for engagement detection.

A WBT in education study provided evidence supporting its usability in increasing students' interest and attention span and evaluating the learning effects. Including only the literature over a decade, this review depicted a transition of WBT from a conceptually driven approach to a class implementation. Despite the limitations, points of importance for practice that emerged in the present study were seen; therefore, key findings suggested that using biosensors to assess mental states and physiological constructs to infer the impact of teaching was feasible. For instance, electroencephalography (EEG) has been used to evaluate brain attention patterns in lessons (sample shown in **Figure 5**) [6]. Brain-to-brain coupling between students and teachers could act as a measure for modeling classroom communication and interactions. These findings reveal the need to incorporate biosensor-integrated technologies into learning processes to enhance teaching effectiveness by providing an interactive manner of delivery. A study conducted by Li [7] found that EEG-based adaptive systems enhance conventional approaches to learning English with an overall accuracy of 98.5%, precision of 97.7%, recall of 98%, and $F1$-score of 98.6%. It also provides the opportunity to tailor individual educational paths based on brain activity to other algorithms.

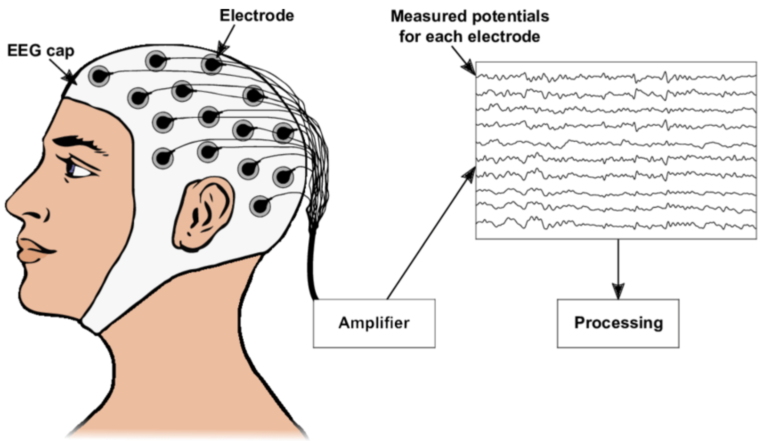

Figure 5. Sketch of how to record electroencephalogram.

Additional example case studies clearly show the benefits of biosensors in an educational process and their influence on increased efficiency of teachers' performances. One such use case is about incorporating galvanic skin response sensors into a big online course of introductory biology, where researchers monitor the level of students' interest in real-time. The study established that skin conductance varied with the student's level of interest and engagement with the content being delivered [8]. From such data, instructors could adapt their strategies based on real-time information on their learners' engagement levels. Apart from enhancing the quality of classroom delivery, the above adaptive approach contributed significantly to enhanced retention of classroom content by students. The applications of biosensors in such a setting show how the teaching profession can be made more efficient by giving teachers real-time information about children's interactions.

Moreover, there is the use of wearable biosensors in physical education environments. Biosensors were used to track students' physiological condition while performing physical tasks in a classroom so that the teachers could help them understand their scores on the tasks done based on the biosensors' data collected from the students [2]. For instance, information such as pulse obtained from students focusing on sports activities helped trainers modify training sessions regarding each student's intensity and endurance. These modifications raised the students' physical performance and helped increase the satisfaction and desire to succeed among the participants. Biosensor technology applied to physical education demonstrates how the usage of big data entails positive improvements in teachers' practices and students' health (**Figure 6**) [2].

Figure 6. Classified wearable sensors for educational purposes according to three major categories according to their placement [9].

In addition, learning with the help of biosensors has been proven effective in improving the language education system. In one of the studies, the educators employed bio-sensor-based emotional reaction monitoring during teaching Japanese language. Teachers can monitor students' affective reactions to instruction to know when to modify instructional methods by using physiological activity as an indirect effect, including heart rate variability [10]. The adaptation paved the way to enhancing instructional arrangements in the classroom, wherein student interaction was enhanced through dealing with emotions surrounding language learning. Therefore, the conclusion drawn from this study emphasizes the importance of including emotion and physiology when developing comprehensible teaching strategies.

Moreover, biosensors can be applied in learning activities. Biosensors have displaced traditional teaching techniques by embracing innovative teaching techniques that engage users. For instance, stress-inducible tests are adaptive tests that change the difficulty level of the questions depending on the stress level of students, enhancing cognitive enhancement. Learning games involving movement, supported by biosensors, encourage positive physical activity and learning, helping to eliminate sedentary habits (shown in **Figure 7**) [11]. In one case study, the presence of skin conductance among biology students during laboratory simulations showed more interest during laboratory activities than in lectures. Such applications are integrated into the document to showcase biosensors' ability to promote active learning and information acquisition.

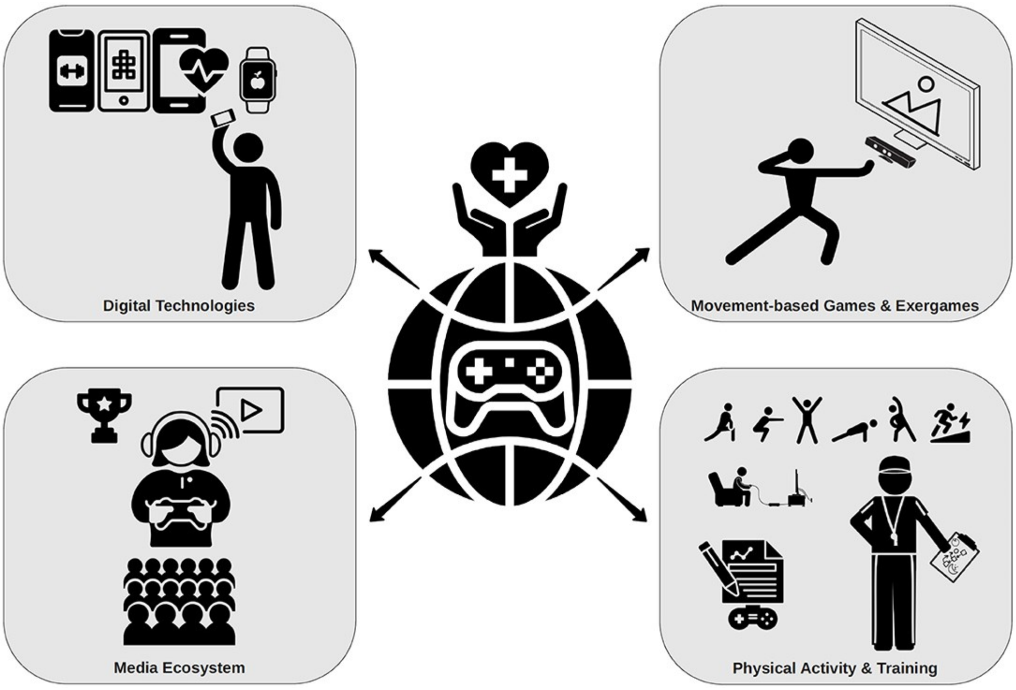

Figure 7. Physical activity and promotion in esports [11].

4. Student engagement and learning outcomes

The use of WBT in learning environments has received much attention in the recent past, especially with emphasis placed on its influence on student engagement and achievement. A systematic review showed that WBT changed students and education in the last decade concerning stress, engagement, cognitive load, and instructional feedback [2]. The review highlighted that biosensors could be used as biometric devices; hence, mentoring authorities such as educators could practice metrics and models that enhance understanding of student performance and learning processes [9]. Since it is possible to monitor the physiology in real-time, biosensors help make education more dynamic than the conventional passive teaching and learning methods, thus improving the teaching efficiency and the students' experience.

Studies gathered suggests that the use of biosensors raises the level of student engagement. For instance, a study showed that students who wear biosensors that track their mood will likely be more engaged during the lectures [2]. The biosensors present a faculty of feedback that can be linked to the improvement of student's self-awareness about their emotions and cognition. Consequently, they can make some adjustments to help them be more interested in what is happening in a classroom. Furthermore, the students' responses also showed they felt motivated when information on how they engaged in their learning activities with biosensors was provided.

An assessment of the performance criteria also provides credence to biosensors' effect on learning results. Other researchers have used the assessment of academic performance, whereby the course tests, completion rate, and level of participation were used to measure performance. Evidence showed that the average scores obtained by students who had a chance to work with biosensor technology were higher than those who did not have such an opportunity [10]. This improvement can be associated with increased coverage and motivation resulting from the quick feedback systems offered by the biosensors. Furthermore, completion rates of the assignments students attained were higher, whereas biosensors enhanced an EMR on timely feedback, which should increase students' likelihood of completing assignments.

Evaluating learning outcomes is a complex process, and another crucial factor in addressing this study is the qualitative student feedback on the biosensors. The compilation of open-ended questions in the survey has given a rich understanding of the impact of biosensor technology on students' learning process. Several students said that due to the real-time feedback, they could tell when they were bored or stressed in class. It lets them use specific coping measures successfully, thus enhancing academic outcomes and quality of life [10]. Opportunities to link engagement metrics to improving learners' emotional well-being call into question the participation of biosensors in the educational process.

Moreover, several studies have been conducted to reinforce the efficiency of biosensor-integrated instruction by using data that explores this technology's effects on student achievements in the long run [11,12]. Using biosensors, students who followed innovation related to biosensors throughout their programs saw increasing performance and development competencies over time. These findings imply that the positive externalities of biosensor technology also transcend the level of interaction with the learning tool to create characteristic conduct among learners [13]. Hence, the physical response experiment can track progress with educators' strategies and design interactions with students that would successfully address and capture students' needs.

Studies have also measured learning accomplishments regarding cognitive ability strengths and knowledge acquisition. An analysis of scores taken on critical thinking instruments also showed that students who used biosensor technology in learning significantly improved their critical thinking compared to the other students who did not interact with biosensor learning tools. Biofeedback intensified the students' meta mnemonic abilities as tracking of internal states facilitated reflection on the content acquired during learning activities [2].

Besides, previous research has looked into specific factors, such as demographic attributes related to student interactivity when using biosensors. Biosensor integration receives more favorable reactions from younger students who are likely to be less exposed to technologically enhanced classrooms [14]. Knowledge of these demographic differences is important for educators who want to increase the effectiveness of the strategies used with different groups of learners. By adopting a diverse participant selection in biosensor-based studies, researchers can enrich the results and uncover the potential for these technologies to improve learning practices.

Moreover, aspects of performance beyond the gross measures of academic achievement are important and valid areas of concern for academicians. A survey by biosensor technology revealed that learners exhibited less stress levels in exams and most other probable stressful events. This helped in appropriately implementing coping mechanisms etherifying the men's health, as evidenced during the strained academic season [14]. The fact that some engagement activity metrics are linked to one's well-being shows that including biosensors in learning/teaching possesses numerous advantages.

5. Biochemical factors in teaching quality

Biomechanical factors shape teaching quality, particularly in physical education and movement-based disciplines. Integrating biomechanical principles into teaching practices can significantly enhance educators' effectiveness in delivering content and improving student outcomes. Research indicates that understanding biomechanics allows teachers to assess and refine movement techniques, leading to better performance and reduced injury risks among students. For instance, a study highlighted the importance of biomechanics in physical education, revealing that teachers who applied biomechanical concepts in their instruction could provide more effective feedback on students' movements. This application improved students' motor skills and fostered a deeper understanding of the mechanics behind physical activities. Consequently, educators with strong biomechanical knowledge are better equipped to create engaging learning environments that promote skill development and student safety.

The influence of biomechanical factors extends beyond the immediate classroom experience; it also impacts the long-term development of students' physical abilities. Research has shown that when educators incorporate biomechanical principles into their curricula, students exhibit improved movement efficiency and technique [14]. For example, the study found that physical education teachers who integrated biomechanics into their lessons could help students develop better running form, enhancing performance and minimizing the risk of injuries associated with improper techniques [14]. This finding underscores the importance of teacher training programs emphasizing biomechanical education, as a solid foundation in biomechanics can empower educators to deliver high-quality instruction that benefits students academically and physically.

Despite the recognized importance of biomechanics in teaching practices, many educators face challenges in effectively applying these principles in their classrooms. A study examining physical education teachers revealed a significant gap between their theoretical knowledge of biomechanics and its practical application in teaching [15]. While most educators acknowledged the value of biomechanics, they often lacked the necessary preparation and resources to integrate these concepts into their instructional strategies effectively. This disconnect highlights the need for comprehensive teacher training programs that focus on bridging the gap between biomechanical theory and practice, ultimately enhancing teaching quality and student outcomes.

Professional development initiatives have emerged as a promising solution to address the challenges faced by educators in applying biomechanics in their teaching practices. Research has demonstrated that continuing education programs based on meaningful learning theory can significantly improve teachers' understanding and application of biomechanical concepts [16]. For instance, participants in a professional development program reported substantial increases in their mastery of core biomechanical principles after engaging in collaborative learning experiences with peers [17]. Such programs enhance teachers' confidence in their biomechanical knowledge and promote a culture of continuous improvement within educational institutions.

The literature also emphasizes the importance of pedagogical strategies that encourage active learning and reflection on biomechanical concepts. Studies have shown that when teachers employ hands-on activities and experiential learning opportunities, students are more likely to engage with the material meaningfully [18,19]. This approach is particularly relevant in biomechanics, where understanding complex concepts requires practical application. Educators can foster a deeper understanding of biomechanics while simultaneously improving teaching quality by incorporating activities that allow students to analyze their movements or those of their peers.

The integration of technology into biomechanics education has also been explored as a means to enhance teaching quality and student engagement. Studies have shown that digital tools like motion analysis software and wearable sensors can provide valuable insights into students' movement patterns and performance metrics [20]. Educators can offer real-time feedback on students' biomechanics by incorporating these technologies into their instruction, allowing for immediate corrections and improvements. This data-driven approach enhances student learning outcomes and promotes a more engaging and interactive classroom environment.

6. Institutional support and implementation

The application of WBT in institutions of learning needs institutions a strong framework that props up the use and application of wearable biosensor technology in the education system. There is a need for institutional framework that comprises training and infrastructural support for educators applying biosensors. WBT is applied in education, educators must undergo efficient training and education regarding interpreting the data gathered by these devices. Due to this training, educators are well equipped with the necessary know-how to ensure the classification can encode maximal valuable information into biosensors for better use in educating learners and achieving impressive learning results [21]. There is also the need to identify practices on biosensor controls, policies and issues of privacy and ethics. Suppose institutions are willing to encourage biosensor realization, as we mentioned before. In that case, schools will be able to lay down solid ground for new patterns of teaching and learning that imply new technological support.

However, other institutional support frameworks should also include assets such as partnerships among stakeholders such as faculty, technical staff, and administrators. There is a need to facilitate communication between these groups to understand the problems and benefits of biosensors' integration. For instance, interdisciplinary prospects can help design the precise biosensor uses in education programs. There is evidence that suggests that institutions that promote collaboration are generally more effective in the deployment of technologies such as biosensors. Suppose the accountability of the biosensors integration in the classroom is positioned as a collective responsibility of faculty members and support staff. In that case, the effectiveness of such an approach can be improved. In addition, offering possibilities to discuss what worked and what did not can encourage educators to employ similar processes while shaping educational processes.

In all these cases, the implementation of biosensor technology has been done using the best practices that would capture the educational institutions. A good example is the SensUs competition, where students from different fields in a team are required to design biosensors for practical purposes. Providing students with biosensors has promoted their innovation and served the purpose of applying innovative technology in education. Some of the students from the Teams who participate in SensUs have noted a high level of team engagement and motivation in completing tasks because those tasks may help others in society. Such competitions help students use the acquired knowledge practically and contribute to developing effective biosensors used in more advanced learning; important for teachers as such competitions shed light on how biosensors can be integrated into curricula successfully.

Another successful implementation strategy is biosensors in conjunction with VR and AR technologies. Incorporating biosensors into VR environments improves students' learning outcomes because the system can monitor the student's physiological responses in real-time during simulations [22]. For example, studies made in medical education proved that with the use of biosensors to monitor students while interacting with VR scenarios, they developed better elasticity of emotion and better cognitive involvement than in conventional lessons. This approach improves the quality of teachers—trainers and prepares students for a world where they must process information based on physiological sensations.

Furthermore, corrective action and assessment of biosensor technology encompass the constant assessment of the pedagogy used in teaching and learning. Organizations that use data to make decisions are better positioned to improve their strategies successively [23]. For instance, a study exposed how teachers in class who track biometric data from the wearables of learners could shift from teaching methods depending on the level of attention from the learners during teaching sessions. From this data, teachers could easily deduce specific patterns within the learners' responses and use the identified patterns in choosing the techniques to use for teaching to enhance the learning process of the students. This cyclical approach highlights the need to incorporate methods to assess the performance of the implemented biosensor technology. Another essential factor that needs consideration is an endorsement of biosensors by the institutional headquarters for proper incorporation into practice. Organizational commitment can express itself in funding initiatives, allocating resources, and producing strategies to promote the innovation of teaching approaches. Studying the relationship between institutional-level support for the use of new technology, such as biosensors, and innovation promoted by faculty has shown that when leaders support the use of technology in teaching, the faculty become willing to trial the technology in their teaching. Also, leadership support enables the availability of funds with which educators can acquire the training and resources required to apply biosensor technology effectively.

Moreover, talents must be able to address the possible barriers to implementation to ensure creative conditions prevail. They include poor cognizance of biosensor applications among the target group, mainly the universities' faculties, and poor understanding of the proposed technologies among the target group. Such challenges can be addressed by offering action-research-based staff development interventions and establishing the respective institutions' biosensors' expertise among educators.

7. Results and discussion

7.1. Presentation of primary data

Analyzing the collected data using SPSS yielded significant insights into the relationship between experience with wearable biosensors, student engagement levels, and academic performance. The dataset comprised 149 participants, with descriptive statistics revealing a mean score of 2.47 (SD = 1.05) for experience with biosensors, indicating moderate usage among students. Engagement levels averaged at 3.06 (SD = 0.37) (shown in **Table 1**), suggesting a generally positive perception of engagement during classes utilizing biosensor technology. Academic performance scores had a mean of 3.25 (SD = 0.58), reflecting a reasonable level of achievement among participants.

Table 1. Descriptive statistics.

Descriptive Statistics						
	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Experience with Wearable Biosensors	149	1.00	5.00	2.4698	1.04516	1.092
Engagement Level	149	2.17	3.83	3.0570	0.37357	0.140
Academic Performance and Learning Outcomes	149	1.33	4.50	3.2472	0.57949	0.336
Biomechanical Factors in Teaching and Learning	149	1.20	5.00	3.3960	0.77581	0.602
Valid *N* (listwise)	149					

The Spearman correlation analysis indicated a significant negative correlation between experience with biosensors and academic performance ($r = -0.503$, $p < 0.01$), suggesting that increased experience with biosensors was associated with lower academic performance scores. However, no significant correlation was found between engagement levels and academic performance ($r = -0.030$, $p = 0.720$) (shown in **Table 2**). These findings suggest that while students may engage positively with biosensor technology, it does not necessarily translate into improved academic outcomes. As revealed in the study, implementing biomechanical theories in teaching and learning practice should receive more attention as it promotes students' interest and enhances learning achievements. According to the correlation analysis findings, there is a negative relationship between the experience of wearable biosensors and biomechanical aspects in teaching and learning (-0.697, $p < 0.01$). With wearable biosensors being used to track physical activity, posture, or stress, deep biomechanical dysfunctions like poor posture or awkward movements associated with physical workload may be exposed. Such information could help correct biomechanical deficiencies and movement patterns during teaching. Also, the presented data proved that biomechanical aspects have a positive significant relationship with academic achievements and the learning process ($r = 0.932$; $p < 0.01$). The heightened correlation between poor biomechanics and learning strongly suggests that a classroom with better posture, movement, and ergonomic design can improve student mental skills and learning by a large degree.

Table 2. Correlations.

Correlations					
		Experience with Wearable Biosensors	**Engagement Level**	**Academic Performance and Learning Outcomes**	**Biomechanical Factors in Teaching and Learning**
Experience with Wearable Biosensors	Pearson Correlation	1	−0.020	−0.565**	−0.697**
	Sig. (2-tailed)		0.808	0.000	0.000
	N	149	149	149	149
Engagement Level	Pearson Correlation	−0.020	1	−0.001	0.006
	Sig. (2-tailed)	0.808		0.995	0.940
	N	149	149	149	149
Academic Performance and Learning Outcomes	Pearson Correlation	−0.565**	−0.001	1	0.932**
	Sig. (2-tailed)	0.000	0.995		0.000
	N	149	149	149	149
Biomechanical Factors in Teaching and Learning	Pearson Correlation	−0.697**	0.006	0.932**	1
	Sig. (2-tailed)	0.000	0.940	0.000	
	N	149	149	149	149

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

The regression analysis further supported these findings, with the model explaining approximately 31.9% of the variance in academic performance (R^2 = 0.319). The ANOVA results indicated that the model was statistically significant ($F(2.146) = 34.237$, $p < 0.001$), confirming that experience with biosensors and engagement levels together significantly predicted academic performance. However, the coefficients revealed that while experience with biosensors had a substantial negative impact on academic performance ($B = -0.313$, $p < 0.001$), engagement levels did not significantly contribute to the model ($B = -0.018$, $p = 0.862$) (shown in **Table 3**). These results highlight a complex relationship where increased reliance on wearable technology may not enhance learning outcomes as intended, prompting further exploration into how these devices are utilized in educational settings. The regression analysis again highlights the biomechanical factors as having good predictive validity; moreover, this variable has the highest correlation with academic achievement ($\beta = 1.045$, $p < 0.001$). On the other hand, engagement level exhibited no correlation with academic performance, having $p = 0.894$, meaning that one should engage beyond the psychological or pedagogy and investigate the physical or biomechanics of teaching and learning. These findings concord with classical biomechanical literature on purposeful posture, comfort, and effective movements to prepare for learning and academic performance.

Table 3. Coefficients.

Coefficients[a]						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	***t***	**Sig.**
		B	**Std. Error**	**Beta**		
1	(Constant)	0.389	0.200		1.943	0.054
	Experience with Wearable Biosensors	0.091	0.022	0.163	4.102	0.000
	Engagement Level	−0.006	0.044	−0.004	−0.133	0.894
	Biomechanical Factors in Teaching and Learning	0.781	0.030	1.045	26.235	0.000

[a] Dependent Variable: Academic Performance and Learning Outcomes.

7.2. Interpretation of findings

This study revealed that wearable biosensors in teaching and learning activities resulted in moderate student engagement but did not raise performance. The pattern of a significantly negative relationship between experience with biosensors and academic performance leads to understanding how these devices are used nowadays and whether they may directly interfere with learning objectives [24]. There is an explanation: while wearable biosensors inform people about physiological conditions, these gadgets can make people dependent on technology rather than motivating self-study or proper study habits [25]. This phenomenon conforms to the biomechanical perspective because forgoing personal self-regulation to rely on the chairs erodes the students' interior propensities for self-sustaining physical aptitudes or ergonomic dispositions pertinent to studying posture or movements. Furthermore, misuse of the biosensors might even lead to practicing wrong biomechanics, that is, postures or movements that are detrimental to cognition and physical health, for example, staying in one position for too long [26].

However, as the students become aware of their body's response to the stimuli for learning, other elements of learning may be affected, including content and method. From a biomechanical perspective, it is essential to know how physiological monitoring devices impact human posture and muscular contractions during learning processes [27]. For example, prolonged biosensor uses results in unconscious postural development or limited mobility, thus decreased blood circulation, fatigue, and impaired cognition [28]. In future implementations, stress should be placed more on cultivating biomechanically healthy student populations while incorporating technologies to support and enhance learning and teaching. Also, since no relationship between the levels of engagement and student performance was discovered suggests that other factors besides physiological engagement should be considered while discussing yields in learning environments.

In a further analysis, data on students' skin conductance and heart rate was reported (**Table 4**).

The study obtained comprehensive physiological measures emphasizing skin conductance level and heart rate variability. The outcomes showed that physically engaged and high arousal students' mean skin conductance level was equal to 0.15 µs in the condition of the interactive lab as opposed to 0.08 µs in the condition of passive lectures. Self-generated activities had an average HR of 95 bpm, while timed Quizzes had a mean of 96 bpm. This data discusses student learning engagement levels to partake in the teaching methodologies of the physiological responses through learning enhancement.

Table 4. Students' skin conductance and heart rate.

Task Type	Mean Skin Conductance (μs)	Mean Heart Rate (bpm)
Interactive Labs	0.15	95
Passive Lectures	0.08	72
Timed Quizzes	0.12	96
Group Discussions	0.1	65

7.3. Comparison with literature

These results contribute to the existing information on biosensor technologies in learning environments, a significant and rapidly developing area of study. For instance, physiological monitoring improves students' knowledge and engagement. However, achievement can only be enhanced by using instructional strategies correctly. Biomechanics offers a broader view by embracing the body's positioning and ergonomics alongside engagement when learning [29]. From a biomechanical perspective, specific postural alignments or suboptimal movements during study sessions affect the learning processes and, as a result, academic performance. Just as investigations revealing the positive impacts of postural optimization and design of ergonomic workspace in enhancing concentration on learning and health confirmed the need to consider physiological and biomechanical perspectives in learning.

As such, in Sathish's [30], the importance of integrating technology into the paradigms of instructing to enhance the learning climate more efficiently remained an essential issue. Contrary to our study, some authors have only revealed positive associations between wearables' engagement indexes and performance results [31]. These differences may be attributed to variations in the research methods or context; for example, studies in learning activities with integrated active learning report greater interest and achievement than traditional teacher-directed recitations. This means that biosensors in wearables could be helpful with teaching methodologies that consider students' compliance as they move around or use the technology. For example, active learning assuming mobility, including standing desks or classroom arrangements that facilitate movement, is consistent with the biomechanical analysis of the need to counteract sedentary behavior and enhance blood flow.

Moreover, previous research indicates that preservice teacher education and instructional modality are essential predictors of teachers' appropriate technology integration into their learning instructional applications [32]. In this regard, if the teachers concerned with educating the students do not get adequate training or information about the biosensor data, they do not get the optimum benefit of such technologies. Hence, teachers should also be trained in biomechanical concepts related to ergonomics, dynamic posture, and active breaks to develop a new approach to creating conditions for enhancing students' learning process. This suggests that district-wide professional learning programs are needed to adequately support experts' learning by incorporating wearable technology and biomechanics.

8. Conclusion and recommendations

8.1. Summary of key findings

This study aimed to investigate the impact of wearable biosensor technology on student engagement and academic performance in educational settings. The primary research questions focused on how experience with biosensors influences student engagement levels and whether this engagement correlates with academic performance. The analysis of quantitative data provided several significant findings. While students reported moderate engagement levels when using biosensors, this engagement did not correlate positively with their academic performance. A notable negative correlation was found between experience with biosensors and academic performance, suggesting that increased reliance on these technologies may not enhance learning outcomes as intended. Additionally, the regression analysis indicated that experience with biosensors significantly predicted academic performance, while engagement levels did not contribute meaningfully to the model. These findings highlight a complex relationship between technology use, student engagement, and academic success, prompting further examination of how biosensors are integrated into educational practices [33].

8.2. Practical recommendations

Some recommendations can be provided to educators and educational institutions based on the results. First and foremost, teachers must reflect on using wearable biosensor technology as part of their teaching approaches. It is recommended that pro-development training focus on how biosensor data should be used while at the same time enhancing content knowledge and critical thinking skills. They should also incorporate effective learning strategies, besides information technology, that encourage students to interact. Further, institutions should foster technology adoption in a way that is supplementary to conventional learning practices [34]. This includes allocating appropriate funds and energy for the educators and students who should guarantee that the wearable biosensors are deployed appropriately.

8.3. Suggestions for future research

To extend the findings of this investigation, more research questions should be posed in several areas in future studies. There is a lack of longitudinal research that might help determine the consequences of wearable biosensor integration on the students' long-term learning behaviors and assessment results. Further research focusing only on the specific pedagogy where biosensors can be integrated will assist in distinguishing effective teaching and learning methods so that the learners' performance will be improved. Further, a more refined examination of various types of biosensors and their respective effects on the various fields of application could be beneficial as well. Moreover, the rationale of wearables is supported by qualitative research that focuses on the student experience and impression of wearable technology to advance the quantitative evidence on its impact on the learning environment.

Despite wearable biosensors being capable of stimulating students' activity in the learning environment, their influence on academic results is rather ambivalent. By following the recommendations mentioned above and carrying out more empirical research on the mentioned subject, educators and institutions can learn how to utilize technology to optimally facilitate various students' learning. The original contribution of this research is found in investigating more complex patterns and processes of connection between technology adoption, utilization, and various forms of performance information that may have implications for future educational practice and development.

8.4. Significance of the study

This research contributes to the literature by meaningfully extending biosensor applications in educational contexts. By constantly monitoring students' functions and facilitating biosensors responses, teaching methodologies can be individualized to meet their needs depending on their psychological conditions. Some of these are that they can capture engagement and stress levels and do this constantly, allowing the educators to modify the approach taken on the go. Furthermore, this research describes biosensors as affected by several fields, such as military training, therapy, and corporate learning. Such findings contribute to the development of electronic education and have policy and practical implications for stakeholders seeking to improve teaching standards.

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References

1. Naresh V, Lee N. A Review on Biosensors and Recent Development of Nanostructured Materials-Enabled Biosensors. Sensors. 2021; 21(4): 1109. doi: 10.3390/s21041109
2. Hernández-Mustieles MA, Lima-Carmona YE, Pacheco-Ramírez MA, et al. Wearable Biosensor Technology in Education: A Systematic Review. Sensors. 2024; 24(8): 2437. doi: 10.3390/s24082437
3. Liu K, Zhou Y. The impact of ergonomics and biomechanics on optimizing learning environments in higher education management. Molecular & Cellular Biomechanics. 2024; 21(3): 396. doi: 10.62617/mcb396
4. Bustos-López M, Cruz-Ramírez N, Guerra-Hernández A, et al. Wearables for Engagement Detection in Learning Environments: A Review. Biosensors. 2022; 12(7): 509. doi: 10.3390/bios12070509
5. Arguel A, Lockyer L, Lipp OV, et al. Inside Out. Journal of Educational Computing Research. 2016; 55(4): 526-551. doi: 10.1177/0735633116674732
6. Light GA, Williams LE, Minow F, et al. Electroencephalography (EEG) and Event-Related Potentials (ERPs) with Human Participants. Current Protocols in Neuroscience. 2010; 52(1). doi: 10.1002/0471142301.ns0625s52
7. Li X. Biosensor technology for adaptive intelligent education systems to enhance personalized English learning. Molecular & Cellular Biomechanics. 2025; 22(1): 912. doi: 10.62617/mcb912
8. Hardy M, Wiebe EN, Grafsgaard JF, et al. Physiological Responses to Events during Training. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2013; 57(1): 2101-2105. doi: 10.1177/1541931213571468
9. Yildiz Durak H. Preparing pre-service teachers to integrate teaching technologies into their classrooms: Examining the effects of teaching environments based on open-ended, hands-on and authentic tasks. Education and Information Technologies. 2021; 26(5): 5365-5387. doi: 10.1007/s10639-021-10511-5

10. Wettstein A, Krähling S, Jenni G, et al. Teachers' Heart Rate Variability and Behavioral Reactions in Aggressive Interactions: Teachers Can Downregulate Their Physiological Arousal, and Progesterone Favors Social Integrative Teacher Responses. European Journal of Investigation in Health, Psychology and Education. 2024; 14(8): 2230-2247. doi: 10.3390/ejihpe14080149
11. Khosravi S, Bailey SG, Parvizi H, et al. Wearable Sensors for Learning Enhancement in Higher Education. Sensors. 2022; 22(19): 7633. doi: 10.3390/s22197633
12. Zhang X, Ding Y, Huang X, et al. Smart Classrooms: How Sensors and AI Are Shaping Educational Paradigms. Sensors. 2024; 24(17): 5487. doi: 10.3390/s24175487
13. Liang PS, Nicolini AM, Ogden KL, Yoon JY. Use of biosensors in secondary education classrooms. Transactions of the ASABE. 2015; 58(2): 181–190. doi: 10.13031/trans.58.10631
14. Alazmi HS, Alemtairy GM. The effects of immersive virtual reality field trips upon student academic achievement, cognitive load, and multimodal presence in a social studies educational context. Education and Information Technologies. 2024; 29(16): 22189-22211. doi: 10.1007/s10639-024-12682-3
15. Chen J, Fu Z, Liu H, et al. Effectiveness of Virtual Reality on Learning Engagement. International Journal of Web-Based Learning and Teaching Technologies. 2023; 19(1): 1-14. doi: 10.4018/ijwltt.334849
16. Antoniou PE, Arfaras G, Pandria N, et al. Biosensor Real-Time Affective Analytics in Virtual and Mixed Reality Medical Education Serious Games: Cohort Study. JMIR Serious Games. 2020; 8(3): e17823. doi: 10.2196/17823
17. Stiles VH, Katene WH. Improving physical education student teachers' knowledge and understanding of applied biomechanical principles through peer collaboration. Physical Education & Sport Pedagogy. 2013; 18(3): 235-255. doi: 10.1080/17408989.2012.666788
18. Cui Z, Wang D. Physical education teaching: A biomechanical perspective of physical education educators and coaches. Molecular & Cellular Biomechanics. 2024; 21(3): 611. doi: 10.62617/mcb611
19. Belmont R, Knudson D, Costa PHL da, et al. Meaningful learning of biomechanical concepts: an experience with physical education teachers in continuing education. Journal of Physical Education. Published online 1989. doi: 10.4025/jphyseduc.v32i1.3263
20. Cojorn K, Sonsupap K. A collaborative professional development and its impact on teachers' ability to foster higher order thinking. Journal of Education and Learning (EduLearn). 2024; 18(2): 561-569. doi: 10.11591/edulearn.v18i2.21182
21. Young MR. Experiential Learning = Hands-On + Minds-On. Marketing Education Review. 2002; 12(1): 43-51. doi: 10.1080/10528008.2002.11488770
22. Kong Y. The Role of Experiential Learning on Students' Motivation and Classroom Engagement. Frontiers in Psychology. 2021; 12. doi: 10.3389/fpsyg.2021.771272
23. Rigozzi CJ, Vio GA, Poronnik P. Application of wearable technologies for player motion analysis in racket sports: A systematic review. International Journal of Sports Science & Coaching. 2022; 18(6): 2321-2346. doi: 10.1177/17479541221138015
24. Saddiqa M, Kirikova M, Magnussen R, et al. Towards Using Sensors as Data Sources in Teaching: Requirements for School Curricula-Compatible Sensors. Complex Systems Informatics and Modeling Quarterly. 2021; (26): 78-93. doi: 10.7250/csimq.2021-26.05
25. Guillen-Sanz H, Checa D, Miguel-Alonso I, et al. A systematic review of wearable biosensor usage in immersive virtual reality experiences. Virtual Reality. 2024; 28(2). doi: 10.1007/s10055-024-00970-9
26. Szukits Á, Móricz P. Towards data-driven decision making: the role of analytical culture and centralization efforts. Review of Managerial Science. 2023; 18(10): 2849-2887. doi: 10.1007/s11846-023-00694-1
27. Huo J. Evaluation of the impact of intelligent logistics systems based on biosensors on food preservation effect. Molecular & Cellular Biomechanics. 2024; 21(2): 460. doi: 10.62617/mcb460
28. Sathish. Digital Learning: A New Paradigm for Teaching and Learning. Shanlax International Journal of English. 2023; 12(S1-Dec): 486-488. doi: 10.34293/rtdh.v12is1-dec.140
29. Pecchinenda A. The Affective Significance of Skin Conductance Activity During a Difficult Problem-solving Task. Cognition & Emotion. 1996; 10(5): 481-504. doi: 10.1080/026999396380123
30. Wollesen B, Schott N, Klotzbier T, et al. Cognitive, physical and emotional determinants of activities of daily living in nursing home residents—a cross-sectional study within the PROCARE-project. European Review of Aging and Physical Activity. 2023; 20(1). doi: 10.1186/s11556-023-00327-2

31. Lu T, Chang C. Biomechanics of human movement and its clinical applications. The Kaohsiung Journal of Medical Sciences. 2012; 28(2S). doi: 10.1016/j.kjms.2011.08.004
32. Wu JY, Ching CTS, Wang HMD, et al. Emerging Wearable Biosensor Technologies for Stress Monitoring and Their Real-World Applications. Biosensors. 2022; 12(12): 1097. doi: 10.3390/bios12121097
33. Hasanain B. The Role of Ergonomic and Human Factors in Sustainable Manufacturing: A Review. Machines. 2024; 12(3): 159. doi: 10.3390/machines12030159
34. Ketelhut S, Martin-Niedecken AL, Zimmermann P, Nigg CR. Physical Activity and Health Promotion in Esports and Gaming–Discussing Unique Opportunities for an Unprecedented Cultural Phenomenon. Frontiers in Sports and Active Living. 2021; 3. doi: 10.3389/fspor.2021.693700