FROM BIOMETRIC WEARABLES TO SUSTAINABLE PEDAGOGY: LINKING SENSORS, AI, AND EDUCATION

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Introduction

This systematic review synthesizes 32 studies that combine wearable biometric sensors (e.g., EEG, HR, GSR) with AI algorithms in educational settings. Most works use machine and deep learning to classify short-term states such as stress, attention, emotions, and activity, often in small, lab-based samples. Evidence shows that these models can reliably detect learners' psychophysiological states, but real-time personalization, longitudinal designs, and integration into intelligent tutoring systems remain rare. The review highlights opportunities for inclusive education and stresses the need to address privacy, ethics, and forthcoming regulations when deploying AI-enabled wearables in schools and universities.

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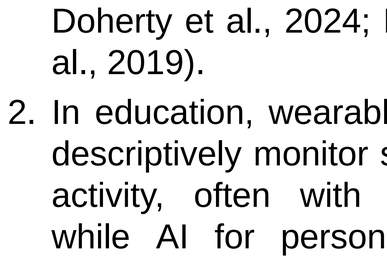
Background and Research Questions

1. Wearable devices now provide reasonably reliable measurements of ECG, HRV, GSR, PPG, and EEG and are widely used in sports medicine, cardiovascular care, and behavioral therapy (Bayoumy et al., 2021; Doherty et al., 2024; Li et al., 2016; Voss et al., 2019).
2. In education, wearables are mostly used to descriptively monitor stress, engagement, or activity, often with single-sensor setups, while AI for personalized learning rarely exploits continuous biometric data (Ahmed et al., 2025; Hernández-Mustieles et al., 2024; Hong et al., 2025; Khosravi et al., 2022).
3. This review maps studies that combine wearables, biometric signals, and AI algorithms in educational settings and outlines their implications for personalized learning.

RQ1 How can biometric data collected via wearable devices and analyzed through AI algorithms provide reliable information in educational contexts?
RQ2 How can these frameworks enable continuous personalization in education?

Characteristics of included studies



(a) Number of included studies categorized by publication type (conference or journal paper).

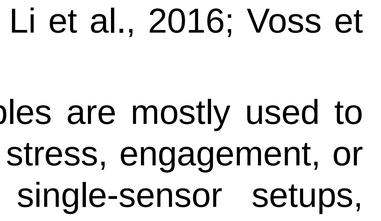
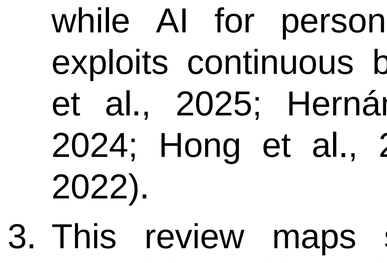


Figure 3. Number of included articles by objective, considering that each article may have several objectives.



(b) Number of included articles by year of publication (2015–2024).

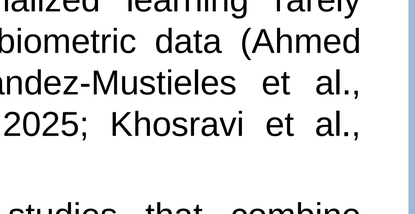


Figure 4. Number of included studies by applied algorithm.

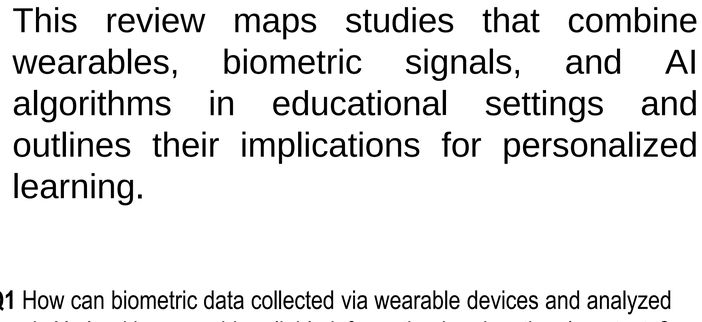
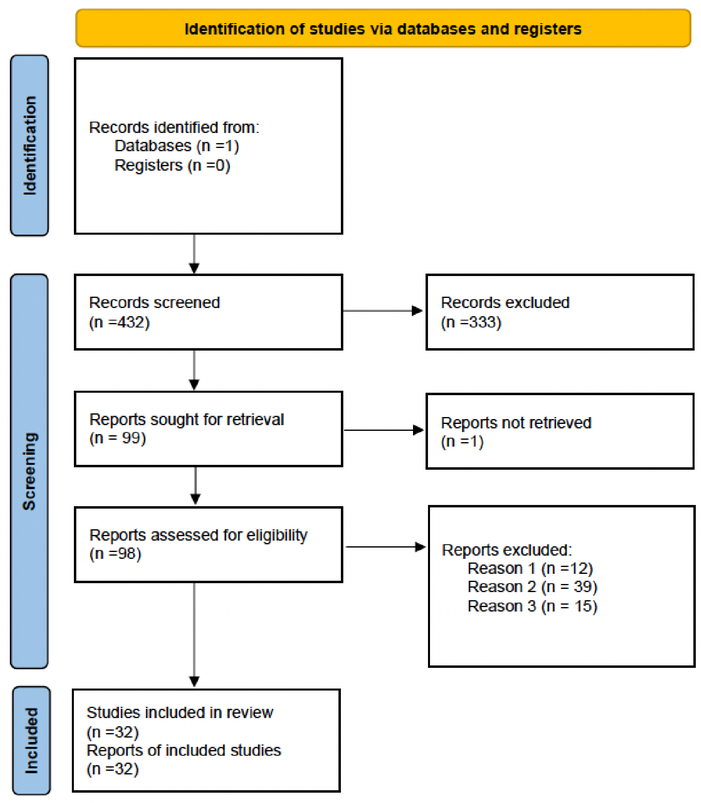


Figure 5. Number of included articles by collected data.

Method



Inclusion criteria	Exclusion criteria
Wearable sensors collecting biometric data	Only public datasets used (no original data collection)
AI / ML algorithms applied to biometric data	No biometrics collected
Educational context (school, university, training)	No AI / ML algorithms used

Results

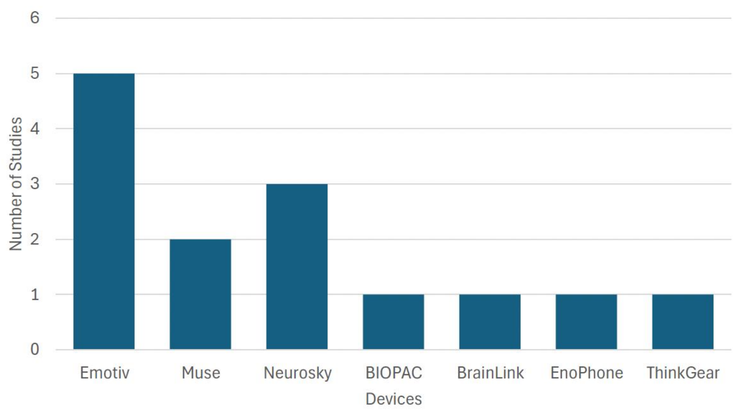


Figure 6. EEG Devices Used Across Studies.

Study	PSD	Time Domain	Wavelets	WVD	Hilbert-Huang	Entropy/Chaos	Band Ratios	Manufacturer Indices
Raković et al. + 2024	1	1	0	0	0	0	0	0
Chen et al. + 2023	1	0	0	0	0	0	0	0
Mohamed et al. + 2020	1	1	0	0	0	0	0	0
Gu + 2024	0	0	0	0	0	0	0	0
Qu et al. + 2018	1	0	0	0	0	0	0	1
Prieto et al. + 2016	0	0	0	0	0	0	0	1
Taherisadr et al. + 2024	0	0	0	1	0	0	0	0
Gao et al. + 2022	0	0	0	0	0	0	0	1
Gupta et al. + 2023	1	1	0	0	0	0	0	0
Guo et al. + 2022	1	0	0	0	0	0	0	1
Aguilar-Herrera et al. + 2021	1	0	0	0	0	0	0	0
Alqahtani et al. + 2021	1	1	0	0	0	0	0	0
Gonzalez-Hernandez et al + 2024	0	0	0	0	0	1	0	0
Chandra et al. + 2024	1	1	0	0	1	0	1	0
Elkerdawy et al. + 2020	1	1	1	0	0	0	0	0

Figure 7. EEG signal characteristics (features) extracted per study

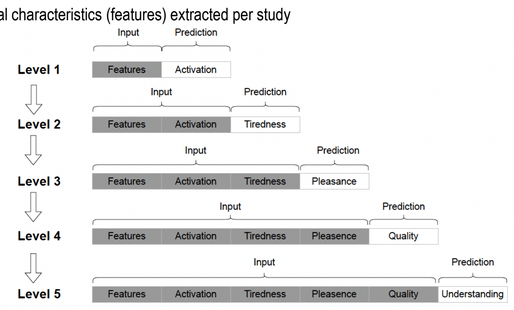


Figure 8. Diagram of the chain model described in [34].

Results

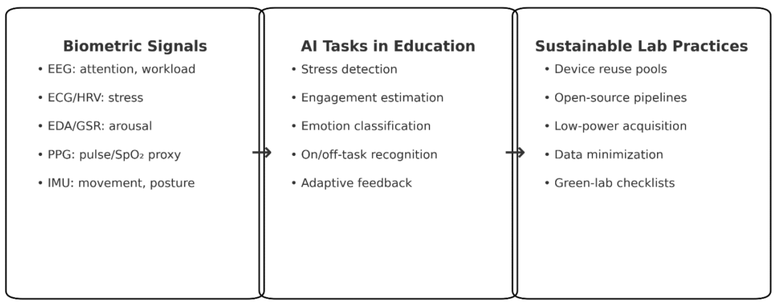


Figure 1. From biometric signals to AI tasks to sustainable lab practices for responsible, real-time learning diagnostics.

Discussion

1. What we know

AI on wearable biometrics is emerging as a distinct line of work that goes beyond descriptive wearable studies in education (Hernández-Mustieles et al., 2024; Hong et al., 2025; Khosravi et al., 2022; Hashim et al., 2022).

ML / DL models on EEG and physiological signals reliably detect stress, attention, and related mental states in classroom-proximate tasks, supporting adaptive support with AI-enabled wearables (Chen & Lee, 2023; Gao et al., 2022; Islam et al., 2021; Zheng et al., 2021; Zhu et al., 2017; Taherisadr et al., 2024).

2. What limits current work

Evidence is dominated by short lab protocols, small samples, and self-reported labels, with weak links to learning outcomes and long-term classroom deployment (Islam et al., 2021; Chen & Lee, 2023; Raković et al., 2024).

Personalization remains mostly at prototype stage and inclusive or collaborative uses are rare, with only a few examples for neurodiverse students and classroom orchestration (Zheng et al., 2021; Prieto et al., 2018; Taherisadr et al., 2024).

3. Where to go next

Ethical and regulatory issues (privacy, user acceptance, EU AI Act compliance) are largely neglected despite highly sensitive biometric data (European Parliament and Council, 2024; Hernández-Mustieles et al., 2024). Future research should tie biometric-driven adaptation to robust educational outcomes, use LLM-based personalization grounded in course knowledge graphs and learner profiles, and integrate privacy-by-design into AI–wearable ecosystems (Ahmed et al., 2025; Meng & Guo, 2025)

Conclusion

Overall takeaway

AI applied to wearable biometrics can reliably detect stress, attention, engagement, emotions, fatigue, and activity in educational settings.

State of the field

Evidence is promising but still prototype-oriented, based on short lab studies, small samples, and heterogeneous protocols, with weak links to actual learning outcomes and classroom practice.

Implications for practice

Biometric signals could inform adaptive support, inclusive education, and real-time classroom orchestration if embedded in intelligent tutoring and learning platforms.

Future directions

Run longitudinal classroom trials, connect biometric-driven adaptation to robust learning gains, and design AI–wearable ecosystems that follow privacy-by-design and regulatory requirements.

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