HYBRID AND EMOTIONALLY AWARE LEARNING ENVIRONMENTS: AN EXPERIMENTAL STUDY ON INTELLIGENT EDUCATIONAL ARCHITECTURES

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ABSTRACT
This experimental study explores the effectiveness of hybrid and emotionally aware learning environments in lower secondary schools. Using a pre-test/post-test design with a randomised control group, the research involved 120 students and integrated quantitative and qualitative data. Results showed improvements in psychological well-being, emotional regulation and school engagement, highlighting the potential of smart, student-centred educational environments oriented towards well-being and relational quality.

KEYWORDS
Smart learning environments; Psychological well-being; Emotional regulation; Student engagement; Multimodal learning analytics.

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1. Introduction

Contemporary schools are undergoing a profound transformation, not only from a technological perspective, but also from pedagogical and cultural standpoints. This transformation forms part of a broader epistemological shift that is reshaping the very way we conceive of knowledge, learning and the role of those involved in educational processes (Morin, 2000; Siemens, 2005). In this context, learning can no longer be interpreted as an exclusively cognitive, linear and individual process, but must be understood as a complex, situated and embodied experience, involving emotional, social and bodily dimensions within a systemic framework (Illeris, 2018; Jarvis, 2006).

Evidence from educational neuroscience has now made it clear that emotions play a crucial role in attentional, mnemonic and motivational processes, directly influencing learning outcomes (Immordino-Yang & Damasio, 2007; Pessoa, 2008). In particular, positive emotions are associated with greater cognitive flexibility and creativity, whilst prolonged negative emotional states can impair concentration and self-regulation (Fredrickson, 2001; Pekrun, 2006). From this perspective, cognition and emotion are not separate dimensions, but deeply interconnected systems that jointly determine the learning experience (Tyng et al., 2017; Immordino-Yang, Darling-Hammond, & Krone, 2019).

In support of this view, the control-value theory of academic emotions (Pekrun, 2006) highlights how the emotions experienced by students are influenced by their perception of control and the value attributed to the task, with direct effects on motivation and performance. Longitudinal studies also confirm that emotional well-being is a significant predictor of academic success and resilience (OECD, 2019; Suldo et al., 2011), reinforcing the idea that affective dimensions constitute a structural, rather than an ancillary, component of educational processes.

At the same time, the evolution of digital technologies has opened up new prospects for the design of intelligent and adaptive learning environments capable

of responding dynamically to students' needs (Holmes et al., 2022). In particular, the integration of physiological and environmental sensors now allows for the collection of real-time data on students' psychophysical states, opening up new avenues of research in the field of multimodal learning analytics (Blikstein & Worsley, 2016; Ochoa & Worsley, 2016).

These technologies enable the monitoring of parameters such as heart rate, heart rate variability (HRV), skin conductance, posture and attention levels, as well as environmental variables such as light levels, temperature and air quality (D'Mello & Kory, 2015; Schneider et al., 2018). However, the interpretation of such data still has room for ambiguity, as similar physiological signals may correspond to different emotional states, making integration with contextual and subjective data necessary (Calvo & D'Mello, 2010; Cacioppo, Tassinary, & Berntson, 2017). Multimodal analysis, if properly designed, nevertheless allows for the inference of emotional and cognitive states with increasing accuracy and the development of adaptive systems based on real-time feedback.

From this perspective, the data collected can be processed using machine learning algorithms and presented in the form of dashboards and summary indicators, which are useful for supporting processes of self-regulation and instructional adaptation (Siemens & Baker, 2012; Baker & Inventado, 2014). Technologies thus function not only as detection tools, but as genuine cognitive and emotional mediators, capable of amplifying the reflective capacities of students and teachers (Luckin et al., 2016; Ifenthaler & Yau, 2020).

'Emotionally aware' learning environments lie at the intersection of affective computing, learning analytics and social-emotional pedagogy. The concept of affective computing (Picard, 1997) refers to the development of systems capable of recognising, interpreting and responding to human emotional states, whilst the field of learning analytics has highlighted the potential of educational data to understand and improve learning processes (Ferguson, 2012). The integration of multimodal data allows for a more comprehensive and dynamic view of the student

experience, overcoming the limitations of traditional measurements (Worsley et al., 2021).

From a pedagogical perspective, the social-emotional learning (SEL) approach emphasises the importance of developing skills such as self-awareness, emotional regulation and empathy (CASEL, 2020) . Recent meta-analyses confirm that SEL programmes produce significant effects on both well-being and academic outcomes (Durlak et al., 2011; Taylor et al., 2017; Corcoran et al., 2018). Despite these developments, the literature still presents significant limitations. Firstly, many studies rely on quasi-experimental designs or laboratory settings, limiting the ecological validity and generalisability of the results (Roll & Wylie, 2016). Secondly, the systematic integration of physiological, behavioural and self-reported data within real school settings remains limited. Finally, unresolved issues remain regarding data ethics, algorithm transparency and the sustainability of technological solutions (Slade & Prinsloo, 2013; Holmes et al., 2022).

In light of these gaps, there is a need for rigorous experimental studies to evaluate the effectiveness of hybrid, emotionally aware learning environments in authentic contexts. This study aims to address this need through a controlled experimental design and an integrated qualitative-quantitative methodological approach. In particular, the study aims to contribute to the existing literature through: (a) the implementation of an intervention in a real-world school setting, (b) the integration of objective and subjective data, and (c) the assessment of effects on well-being, self-regulation and engagement.

The theoretical foundation of the study is based on three main conceptual frameworks. Social-emotional learning (SEL) theory provides the framework for understanding the role of emotional skills; the embodied cognition paradigm highlights how cognitive processes emerge from the interaction between body, environment and mind (Wilson, 2002; Barsalou, 2008); finally, affective computing offers tools for the detection and analysis of emotions in real time. The integration

of these perspectives allows us to conceive of the learning environment as a complex and adaptive system.

In this view, well-being is not an ancillary element, but a structural condition for effective learning (Biesta, 2020). This implies the need to design educational environments capable of integrating cognitive, emotional and physical dimensions with a view to sustainability and inclusion. This study is situated within this framework, proposing and testing a model of a hybrid and emotionally aware learning environment, grounded in solid theoretical foundations and supported by empirical evidence.

2. Aims and hypotheses of the study

The main aim of the study is to assess the impact of a sensor-enabled hybrid learning environment on students' psychological and physical well-being and on the socio-emotional climate of the classroom, using a multidimensional approach that integrates subjective, behavioural and physiological indicators.

In line with this objective, the study aims to: Based on the theoretical framework, the following hypotheses are formulated:

1. analyse changes in levels of perceived psychological well-being (WHO-5);
2. assess the degree of academic engagement in its cognitive, emotional and behavioural components;
3. examine changes in emotional regulation processes (DERS);
4. analyse changes in the classroom climate (CES);
5. explore the subjective perceptions of students and teachers regarding the learning experience.

- H1 (primary outcome): students in the experimental group will show a significantly greater increase in levels of psychological well-being (WHO-5) compared to the control group between T0 and T1;
- H2: the experimental group will show significantly higher levels of school engagement than the control group, across all its dimensions;

- H3: students in the experimental group will show a significant reduction in emotional regulation difficulties (DERS) compared to the control group;
- H4: the experimental group will show a significant improvement in classroom climate (CES) compared to the control group;
- H5 (exploratory hypothesis): the qualitative data will highlight a positive perception of the emotionally aware learning environment in terms of support for well-being, emotional awareness and participation.

3. Methodology

Research design

The study employs a randomised controlled trial (RCT) design, widely recognised in the literature as the gold standard for evaluating the effectiveness of educational interventions (Shadish, Cook & Campbell, 2002; Slavin, 2008). This approach allows causal relationships to be established between the intervention and the observed outcomes, minimising the influence of confounding variables and selection bias. Participants were randomly assigned to the experimental group (EG; n = 60) or the control group (CG; n = 60) using a simple randomisation procedure, implemented through the automatic generation of random numbers. The allocation process was managed to ensure baseline equivalence between the groups with regard to key variables such as age, gender, academic performance and levels of psychological well-being measured in the pre-test phase, in line with methodological recommendations for controlled educational studies (Torgerson & Torgerson, 2008).

The design adopted is a pre-test/post-test design with a parallel control group, which involves measuring the dependent variables at two distinct time points: a pre-intervention phase (T0), aimed at establishing an initial baseline, and a post-intervention phase (T1), aimed at measuring changes attributable to the implementation of the emotionally aware learning environment. This structure allows for the observation of both intra-group changes over time and inter-group

differences, thereby strengthening the internal validity of the study (Campbell & Stanley, 1963).

To further enhance the robustness of the experimental design, specific methodological control strategies were adopted. Firstly, the educational context was kept constant between the two groups, ensuring that the control group followed the same curricular activities as the experimental group, with the exception of the introduction of innovative technological and pedagogical components. Secondly, the teachers involved were trained to follow standardised teaching protocols, in order to reduce variability linked to teaching style (Hattie, 2009).

Although it was not possible to implement a double-blind design, forms of partial single-blind testing were adopted: the external evaluators responsible for data analysis were unaware of the participants' group allocation, thereby reducing the risk of interpretative bias (Cook & Campbell, 1979).

The design also included monitoring of treatment fidelity through observational checklists and systematic recordings, in order to verify that the experimental conditions were implemented in a consistent and replicable manner (Dane & Schneider, 1998).

Finally, the methodological approach adopted is a mixed-methods embedded design, in which the quantitative component forms the main axis of the analysis, whilst qualitative data are integrated to provide a deeper understanding of the processes underlying the observed results (Creswell & Plano Clark, 2017). This integration allows for the triangulation of evidence and increases the overall validity of the study.

In summary, the experimental design adopted combines methodological rigour and ecological validity, allowing for a reliable assessment of the intervention's impact in a real-world school setting.

Sample

The sample under study consists of 120 students (n = 120), aged between 11 and 13, enrolled at a lower secondary school located in a medium-sized urban area. The participants were divided into two groups of equal size: the experimental group (EG; n = 60) and the control group (CG; n = 60).

The choice of this age group is based on specific theoretical and methodological considerations: pre-adolescence represents a crucial stage of development, characterised by significant emotional, cognitive and social changes, which make students particularly receptive to educational interventions focused on well-being and emotional regulation (Steinberg, 2014; Eccles & Roeser, 2011).

Participants were recruited on a voluntary basis, following consultation with the school and provision of detailed information to families regarding the study's objectives and procedures. In line with the ethical principles of educational research (BERA, 2018), informed consent was obtained from parents or legal guardians, as well as the students' assent.

Inclusion criteria required regular school attendance and the absence of severe clinical conditions that might interfere with participation in the study. Students diagnosed with serious neurological or psychiatric disorders and those with an absence rate exceeding 20% of the intervention period were excluded, in order to ensure treatment adherence and the quality of the data collected (Dane & Schneider, 1998).

Preliminary analysis of the data collected during the pre-test phase confirmed the initial equivalence between the two groups with regard to key variables such as age, gender, academic performance, psychological well-being and engagement, thereby ensuring the internal validity of the study (Torgerson & Torgerson, 2008). In terms of sample size, the sample of 120 participants is adequate for conducting inferential statistical analyses with sufficient statistical power (Cohen, 1988).

Data collection tools

The choice of data collection tools was guided by the need to ensure high standards of reliability, validity and theoretical consistency with the study's objectives. In line with a mixed-methods approach, standardised quantitative instruments, objective physiological measures and qualitative techniques were integrated (Creswell & Plano Clark, 2017).

- *Quantitative instruments*

To measure psychological and contextual variables, instruments widely validated in the international literature were used.

The WHO-5 Well-Being Index (Topp et al., 2015) was used to measure perceived psychological well-being. The scale, comprising five items, exhibits high internal reliability ($\alpha > .80$) and good sensitivity to change (Bech, 2004).

To assess school engagement, the Student Engagement Scale (Fredricks et al., 2005) was used, which distinguishes between cognitive, emotional and behavioural dimensions, with reliability levels ranging from $\alpha = .70$ to $\alpha = .90$. Engagement represents a key variable as a mediator between well-being and learning (Appleton et al., 2008).

The Difficulties in Emotion Regulation Scale (DERS) (Gratz & Roemer, 2004) was used to analyse difficulties in emotional regulation, demonstrating high internal consistency ($\alpha > .85$) and validity in adolescent populations (Neumann et al., 2010).

To measure classroom climate, the Classroom Environment Scale (CES) (Moos & Trickett, 1987) was adopted, which assesses dimensions such as cohesion, support and organisation (Fraser, 2012).

- *Physiological measures*

In order to supplement self-report data with objective indicators, physiological measures were collected using non-invasive wearable devices. Specifically, heart rate (HR) and heart rate variability (HRV) were monitored, as these are considered reliable indicators of physiological arousal and stress (Shaffer & Ginsberg, 2017). HRV serves as an index of the nervous system's capacity for autonomic regulation and flexibility, linked to processes of emotional self-regulation (Thayer et al., 2012).

Integrating physiological data with psychometric measures helps reduce the risk of subjective bias and provides a more comprehensive assessment of students' experiences (D'Mello & Kory, 2015).

- *Qualitative tools*

Alongside quantitative measures, qualitative methodologies were adopted to explore the experiential dimension of the intervention.

Focus groups were conducted with students to explore perceptions and emotional experiences (Krueger & Casey, 2015). In parallel, semi-structured interviews were carried out with teachers to analyse their role in implementing the intervention. Finally, systematic classroom observation was carried out, based on structured protocols, to record behaviours and relational dynamics (Angrosino, 2007). Overall, the integration of quantitative, physiological and qualitative tools allows for methodological triangulation that strengthens the validity of the study (Greene et al., 1989).

3. Description of the intervention

The intervention, lasting a total of eight weeks, was designed as an integrated, multi-level system aimed at having a coordinated impact on students' physical and mental wellbeing, engagement and emotional regulation. It coherently combines three interdependent dimensions: technological, environmental and educational-relational. Unlike additive approaches, the intervention is not limited to the introduction of technological devices, but configures the learning environment as an adaptive and responsive ecosystem, capable of detecting signals from students and the context, interpreting them and returning them in the form of feedback useful for supporting processes of self-regulation, attention and the quality of interactions. This approach falls within the framework of smart learning environments, understood as environments capable of dynamically adapting to students' needs and supporting forms of personalised and socially mediated learning (Koper, 2014; Huang, Yang & Zheng, 2013). At the same time, the

intervention is grounded in the evidence from affective computing, which highlights the possibility of inferring emotional states from physiological and behavioural data (Picard, 1997; Calvo & D'Mello, 2010; D'Mello & Graesser, 2015), and on the socio-emotional learning paradigm, which recognises the central role of emotional and relational skills in learning processes (CASEL, 2020; Durlak et al., 2011; Jones & Kahn, 2017). The intervention was structured in three phases: (a) baseline, (b) implementation, (c) evaluation, following a progressive approach and methodological control consistent with the experimental design adopted.

Baseline phase

The baseline phase (week 1) served a dual purpose: to establish the initial levels of the variables under study and to ensure a gradual transition to the experimental setting, thereby reducing the risk of a *novelty effect* (Clark, 1983; Bower, 2019). Quantitatively, the psychometric scales specified in the protocol (well-being, engagement, emotional regulation, classroom climate) were administered under standardised conditions. Concurrently, initial measurements of physiological parameters (HR and HRV) were taken during normal school activities. At the operational level, a familiarisation phase with the wearable devices was initiated, accompanied by transparent communication to students regarding the aims, methods of use and data protection, in line with models of technology acceptance (Davis, 1989; Teo, 2011). It was made clear that the data would not be used for individual assessment purposes. In parallel, teachers took part in an initial training session focused on the pedagogical interpretation of data and the reflective use of the dashboard, avoiding deterministic or technocentric approaches (Ertmer & Ottenbreit-Leftwich, 2010; Mishra & Koehler, 2006). Finally, a systematic observation of classroom dynamics (pace, interactions, attention) was conducted, serving both to establish a baseline and to calibrate the intervention.

Implementation phase

The implementation phase (weeks 2–7) formed the core of the intervention and was structured as a gradual integration of four components:

1. environmental monitoring
2. physiological monitoring
3. teacher dashboard
4. socio-emotional teaching practices

The approach adopted is based on the principle of complementarity between data collection and intervention: the data collected do not serve a descriptive function, but support micro-adjustments to teaching and the environment (Aarts & de Ruyter, 2009; Cook, Augusto & Jakkula, 2009).

Environmental monitoring

The classroom was equipped with sensors for the continuous monitoring of light levels, noise and air quality (CO_2). These variables were selected on the basis of evidence demonstrating their impact on attention, cognitive performance and well-being (Barrett et al., 2015; Choi et al., 2014; Mendell & Heath, 2005).

The environmental data were presented in summary form and used by teachers to take immediate action (e.g. ventilation, noise management, breaks), making the environment an active teaching variable.

Physiological monitoring

Students in the experimental group used wearable devices to measure heart rate (HR) and heart rate variability (HRV), indicators associated with stress and self-regulation (Porges, 2011; Thayer et al., 2012; Shaffer & Ginsberg, 2017).

The data were used exclusively in aggregated and contextual form, avoiding individual or diagnostic interpretations, in line with ethical recommendations on the use of biometric data (Williamson, 2017; Prinsloo & Slade, 2017).

Teacher dashboard

Environmental and physiological data were integrated into a dashboard providing summary indicators relating to:

- · group engagement
- · environmental quality
- · signs of fatigue

The design is inspired by action-oriented learning analytics (Knight et al., 2014; Ifenthaler & Yau, 2020), providing non-prescriptive operational suggestions.
The teacher retains a central interpretative role, avoiding automated decision-making processes (Selwyn, 2019; Williamson & Eynon, 2020).

Multisensory technologies

The environment has been enhanced with:

- · adaptive lighting
- · controlled soundscapes

These elements have been used contextually to support attention and emotional regulation, in line with studies on the physical environment and learning (Barrett et al., 2015; Klatte et al., 2013).

Social-emotional learning activities

The intervention incorporated SEL-oriented teaching routines:

- · breathing and mindfulness exercises
- · emotional check-ins
- · cooperative activities
- · reflective debriefings

These practices are supported by empirical evidence on self-regulation and classroom climate (Zenner et al., 2014; Klingbeil et al., 2017; Johnson & Johnson, 2009; Gillies, 2016).

Timeline

Implementation was gradual:

· Week 2: observation and minimal activation
· Week 3: initial teaching adaptations
· Week 4: multisensory integration
· Week 5: reinforcement of the socio-emotional dimension
· Week 6: personalisation
· Week 7: consolidation

This structure ensured sustainability and reduced the novelty effect.

Evaluation phase

Week 8 was dedicated to post-intervention data collection (T1), replicating baseline conditions to ensure comparability.

The quantitative scales were administered again and physiological data were collected. In parallel, the following were carried out:

· focus groups with students
· interviews with teachers

These data allowed for the integration of quantitative results and qualitative interpretations.

The sustainability of the intervention was also assessed, a critical element in educational innovations (Cuban, 2001; Howard et al., 2016).

Pedagogical rationale

The intervention is based on an ecological and multi-level approach to school well-being, understood as an emergent property of the interaction between:

- · the individual
- · the group
- · the environment
- · teaching practices

Technology is conceived as a mediator rather than an end in itself, in line with a critical pedagogical perspective (Biesta, 2020).

The main innovation lies in the integration of:

- · objective data
- · teacher interpretation
- · environmental regulation
- · socio-emotional practices

Consistent with the literature, interventions of this type are most effective when they act simultaneously across multiple levels of the education system (Weare & Nind, 2011; Cefai et al., 2021).

The data analysis was designed in line with the mixed-methods approach adopted in the study and with the research hypotheses formulated (H1–H4), with the aim of integrating quantitative and qualitative evidence into a unified, methodologically sound and theoretically grounded interpretative framework. In line with the relevant literature, the integration of numerical and textual data was aimed not only at verifying the effects of the intervention, but also at understanding the processes through which these effects manifested themselves (Creswell & Plano Clark, 2017; Greene et al., 1989).

The analysis was structured across three complementary levels: (a) quantitative analysis of outcomes in relation to the hypotheses, (b) qualitative analysis of processes and perceptions, (c) integration of the results through triangulation.

4. Data analysis

Quantitative analysis

The quantitative analysis was conducted in accordance with the pre-test/post-test experimental design with a control group, in order to test the following hypotheses:

- H1: the experimental group shows a significant improvement in levels of psychological well-being compared to the control group;
- H2: the experimental group shows a significant increase in engagement;
- H3: the experimental group shows an improvement in emotional regulation;
- H4: the experimental group shows an improvement in the class's socio-emotional climate.

For each dependent variable associated with the hypotheses (WHO-5 for H1, Student Engagement Scale for H2, DERS for H3, CES for H4, in addition to physiological indicators), a repeated-measures analysis of variance with a mixed design (mixed-design ANOVA) was applied, with:

- within-subjects factor: time (T0 vs T1);
- between-subjects factor: group (GE vs GC).

The main focus was on the time × group interaction effect, considered a key indicator for testing the hypotheses. A statistically significant interaction was interpreted as evidence of a differential effect of the intervention on the experimental group compared to the control group (Field, 2018; Tabachnick & Fidell, 2013).

To complement the main analysis, the following were conducted:

· paired t-tests, to verify intra-group changes (T0–T1) for each hypothesis;
· independent samples t-tests, for comparisons between GE and GC at the post-test.

Before performing the inferential analyses, the statistical assumptions were checked:

· normality of distributions (Shapiro-Wilk test);
· homogeneity of variances (Levene's test);
· sphericity, where applicable (Mauchly's test).

In the event of a violation of the assumptions, appropriate corrections (e.g. Greenhouse-Geisser) or alternative tests were applied, in line with methodological recommendations (Girden, 1992).
For each analysis, in addition to the p-values, the following effect size indices were calculated:

· Cohen's d for comparisons between means;
· partial eta-squared ($\eta^2 p$) for ANOVA.

These indices were used to interpret the practical relevance of the observed effects, moving beyond an interpretation based solely on statistical significance (Cohen, 1988; Lakens, 2013). Descriptive statistics (mean, standard deviation and 95% confidence intervals) were also calculated for all variables to ensure transparency and replicability. In line with the exploratory objectives of the study, correlations between variables (e.g. well-being, engagement and emotional regulation) were also analysed using Pearson's coefficients, to investigate possible relationships between the dimensions covered by the hypotheses. Missing data were managed using appropriate strategies (complete case analysis and, where necessary, imputation), in order to preserve the consistency of the dataset and reduce potential biases (Little & Rubin, 2019).

Qualitative analysis

The qualitative analysis was designed to explore the processes underlying the quantitative results and to provide interpretative evidence to support or clarify hypotheses H1–H4.

A thematic analysis approach (Braun & Clarke, 2006) was adopted and applied to the transcripts of:

· focus groups with students;

· semi-structured interviews with teachers;

· systematic classroom observations.

The analytical process was divided into five stages:

1. familiarisation with the data;
2. initial coding of units of meaning;
3. construction of themes;
4. review and definition of themes;
5. interpretative analysis with selection of significant extracts.

The analysis followed an integrated approach:

· inductive, to derive categories directly from the data;

· deductive, to link the themes to the theoretical dimensions and hypotheses of the study (well-being, engagement, emotional regulation, classroom climate).

In particular, the themes that emerged were related to the hypotheses:

· perceptions of greater well-being → H1;

· increased participation and engagement → H2;

· self-regulation strategies and emotional awareness → H3;

· quality of relationships and classroom climate → H4.

To ensure the reliability of the analysis, a double coding procedure was adopted on part of the corpus, involving comparison between researchers and the resolution of discrepancies through consensus (Miles, Huberman & Saldaña, 2014).

Data integration and triangulation

The integration of quantitative and qualitative data was achieved through a systematic process of triangulation, with the aim of strengthening the validity of the conclusions and verifying the consistency between results and hypotheses (Denzin, 1978).

Triangulation was structured across three levels:

- methodological: integration of quantitative, physiological and qualitative data;
- sources: comparison between students, teachers and observers;
- theoretical: interpretation in the light of different conceptual frameworks.

In practice, the quantitative results were used to test hypotheses H1–H4, whilst the qualitative data enabled the interpretation of the mechanisms underlying the observed changes.

For example:

- any improvements in well-being (H1) were analysed alongside students' accounts of comfort and their perception of the environment;
- variations in engagement (H2) were interpreted in the light of observations on participatory dynamics;
- changes in emotional regulation (H3) were linked to the mindfulness practices introduced;
- changes in classroom atmosphere (H4) were examined through observed interactions and teachers' perceptions.

This integration made it possible to move beyond a reductionist interpretation of the results, offering a coherent, multi-level interpretative framework (Johnson & Onwuegbuzie, 2004).

Validity and reliability of the analysis

The methodological quality of the analysis was ensured through specific strategies for both components.

For the quantitative component, the use of validated instruments and statistical techniques appropriate to the experimental design ensured adequate levels of internal validity.

For the qualitative component, the criteria of Lincoln and Guba (1985) were adopted:

- credibility, reinforced through triangulation and peer review;
- generalizability, supported by a detailed description of the context;
- consistency, guaranteed by a transparent and systematic analytical process.

Overall, the integrated approach made it possible to rigorously test the research hypotheses and, at the same time, to understand the underlying educational processes, offering a comprehensive and methodologically sound interpretation of the intervention's impact.

5. Results

In order to provide a systematic and interpretatively coherent presentation of the study's findings, the results are presented by distinguishing between quantitative and qualitative evidence, in line with the mixed-methods approach adopted. Specifically, this section is structured according to the research hypotheses (H1–H4), thereby highlighting the impact of the intervention on the various dimensions analysed.

Quantitative results

The quantitative analysis, conducted using repeated-measures ANOVA with a mixed design (time × group), revealed a significant effect of the intervention for all the main variables considered. In particular, for each dimension analysed, a significant interaction emerged between time (T0–T1) and group (EG vs CG), indicating that the changes observed in the experimental group differ systematically from those in the control group. These results broadly support hypotheses H1–H4, highlighting a positive impact of the emotionally aware learning environment.

H1 – Psychological well-being (WHO-5)

Table 1: Psychological well-being (WHO-5)

Group	T0 Average (DS)	T1 Average (DS)	Δ	p	Cohen's d
Experimental	52.3 (10.4)	68.7 (9.8)	+16.4	< .001	0.72
Control	51.8 (11.1)	54.2 (10.6)	+2.4	n.s.	0.18

With regard to hypothesis H1, the results show a significant increase in psychological well-being in the experimental group, compared with minimal changes in the control group. The time × group interaction is significant ($p < .001$), indicating that the observed improvement is attributable to the intervention.

The effect size (Cohen's $d = 0.72$) falls within the medium-to-high range, suggesting that the change is not only statistically but also practically significant. This finding indicates that the emotionally aware learning environment contributed substantially to improving students' perception of well-being.

H3 – Emotional regulation (DERS)

Table 2: Emotional regulation (DERS)

Group	T0 Average (DS)	T1 Average (DS)	Δ	p	Cohen's d
Experimental	88.5 (12.3)	72.1 (11.7)	-16.4	< .001	0.68
Control	87.9 (13.1)	84.6 (12.5)	-3.3	n.s.	0.21

Note: Lower scores indicate better emotional regulation.

With regard to hypothesis H3, the data show a significant reduction in difficulties with emotional regulation in the experimental group, whilst the control group

shows no significant changes. The time × group interaction effect is significant ($p < .001$). Analysis of the sub-dimensions reveals particularly marked improvements in impulse control and access to regulatory strategies, suggesting that the intervention specifically influenced self-regulation processes. The effect size ($d = 0.68$) indicates a moderate-to-large effect.

H2 – Academic engagement (Student Engagement Scale)

Table 3: Academic engagement

Dimension	Group	T0 Average (DS)	T1 Average (DS)	Δ	p
Cognitive	Sper.	3.1 (0.6)	3.6 (0.5)	+0.5	< .01
	Cont.	3.0 (0.7)	3.2 (0.6)	+0.2	n.s.
Emotional	Sper.	2.9 (0.7)	3.7 (0.6)	+0.8	< .001
	Cont.	2.8 (0.6)	3.0 (0.7)	+0.2	n.s.
Behavioural	Sper.	3.2 (0.5)	3.8 (0.4)	+0.6	< .01
	Cont.	3.1 (0.6)	3.3 (0.5)	+0.2	n.s.

With regard to hypothesis H2, the results show a significant increase in engagement across all its components in the experimental group. The effect is particularly pronounced in the emotional dimension, followed by the behavioural dimension, whilst the control group shows no significant changes.

These findings suggest that the intervention fostered not only greater active participation but also a deeper emotional engagement in learning activities.

H4 – Classroom climate (CES)

Table 4: Classroom climate (CES)

Dimension	Group	T0 Average (DS)	T1 Average (DS)	Δ	p
cohesion	Exper.	3.0 (0.5)	3.8 (0.4)	+0.8	< .001
	Cont.	3.1 (0.6)	3.2 (0.5)	+0.1	n.s.
Support	Exper.	2.8 (0.6)	3.7 (0.5)	+0.9	< .001
	Cont.	2.9 (0.5)	3.1 (0.6)	+0.2	n.s.
Engagement	Exper.	3.1 (0.5)	3.9 (0.4)	+0.8	< .001
	Cont.	3.0 (0.6)	3.2 (0.5)	+0.2	n.s.

The results relating to hypothesis H4 indicate a significant improvement in the socio-emotional climate within the experimental group, with notable increases in

the dimensions of cohesion, support and engagement. The control group shows no significant changes.

This data suggests that the intervention produced systemic effects, influencing not only individual dimensions but also the relational dynamics of the class group.

Physiological indicators (convergent evidence)

Table 5: Physiological indicators

Variable	Group	T0 Average (DS)	T1 Average (DS)	Δ	p
Heart rate (bpm)	Sper.	82.4 (6.8)	76.1 (5.9)	-6.3	< .01
	Cont.	81.9 (7.1)	80.2 (6.7)	-1.7	n.s.
HRV (ms)	Sper.	38.5 (10.2)	52.7 (11.4)	+14.2	< .001
	Cont.	39.1 (9.8)	41.3 (10.1)	+2.2	n.s.

Physiological indicators show a reduction in stress-related arousal (heart rate) and a significant increase in HRV in the experimental group. These results provide objective evidence consistent with the self-report data, reinforcing the interpretation of the intervention's effectiveness.

Qualitative results

The qualitative analysis allowed for a deeper exploration of the processes underlying the quantitative results, offering interpretative evidence in relation to hypotheses H1–H4.

Perceived well-being (H1)

Students describe the environment as "calmer", "less stressful" and "easier to concentrate in", suggesting a perceived transformation consistent with the increase in WHO-5 scores.

Emotional awareness and regulation (H3)

Narratives emerged regarding a greater ability to recognise and manage emotional states ("when I got agitated, I was able to calm down"), in line with the reduction in DERS scores.

Engagement (H2)

Students report greater interest and participation ("it engaged me more", "time passed more quickly"), whilst observations confirm an increase in active participation.

Classroom atmosphere (H4)

An improvement in peer relationships is highlighted ("fewer arguments", "more collaboration"), also confirmed by teachers.

Role of technology and teaching

Technology is perceived as supportive and non-intrusive, whilst teachers report a greater ability to read and manage the class group, indicating an impact on professional practice as well.

Synthesis of results

The triangulation of quantitative and qualitative data reveals a strong convergence of results supporting hypotheses H1–H4.

In particular:

- the improvement in well-being (H1) is consistent with the perception of a more regulated environment;
- the increase in engagement (H2) is associated with more dynamic and responsive teaching practices;
- the reduction in emotional difficulties (H3) is reflected in the development of self-regulation strategies;
- the improvement in the learning climate (H4) emerges in both the CES data and the narratives.

Overall, the results suggest that the intervention triggered a multi-level transformation process, simultaneously affecting individual, relational and environmental dimensions, in line with an ecosystemic conception of learning.

6. Discussion

The results of this study provide converging empirical evidence in support of the hypothesis that hybrid, sensor-enabled and emotionally aware learning environments can have a significant impact on students' psychological and physical well-being and on the quality of the classroom's socio-relational climate. The effectiveness of the intervention emerges consistently from the triangulation of quantitative, physiological and qualitative data, outlining a picture of change that appears both measurable and interpretatively grounded. Firstly, the significant increase in psychological well-being scores (WHO-5) in the experimental group suggests a substantial impact of the intervention on students' subjective perception of balance, vitality and satisfaction. This evidence is consistent with the international literature, which recognises school well-being as an outcome emerging from the quality of the learning environment and the opportunities for socio-emotional support provided (OECD, 2019; Suldo et al., 2011; Roffey, 2012). In this sense, the results reinforce the idea that well-being is not an incidental variable, but a structural component of the educational experience. At the same time, the significant reduction in difficulties with emotional regulation (DERS) indicates that the intervention had an impact not only at the perceptual level but also on the development of self-regulatory skills. This finding is particularly relevant in light of the literature on emotional regulation, which identifies it as one of the main predictors of adaptive functioning in educational and social contexts (Gross, 2015; Zimmerman, 2002). The integration of mindfulness practices, guided reflection sessions and environmental feedback appears to have helped foster processes of awareness and management of internal states, in line with recent studies highlighting the effectiveness of integrated socio-emotional interventions in school settings (Schonert-Reichl, 2017). The increase in school engagement, particularly in its emotional and behavioural dimensions, confirms the close interrelationship between well-being and active participation. Students in the experimental group demonstrated higher levels of involvement, interest and

persistence in tasks, empirically supporting the hypothesis that engagement and well-being function as mutually reinforcing dimensions (Fredricks et al., 2005; Appleton et al., 2008). This finding is also consistent with contemporary motivational models, which emphasise the role of environmental and relational conditions in supporting student engagement (Skinner & Pitzer, 2012). At the systemic level, the findings regarding classroom climate reveal a significant improvement in the dimensions of cohesion, mutual support and engagement. This suggests that the intervention did not act exclusively at the individual level, but had an impact on the relational dynamics of the class group, contributing to the creation of a context perceived as safer, more collaborative and more inclusive. These findings are consistent with the literature on classroom climate, which highlights the central role of relationships in promoting well-being and learning (Fraser, 2012; Wentzel, 2010). Particularly relevant is the contribution of physiological data, which show a reduction in stress-related arousal (heart rate) and an increase in heart rate variability (HRV). The convergence between physiological and psychometric indicators strengthens the internal validity of the results, suggesting that the observed changes are not solely self-reported but are also reflected at the neurophysiological level. This finding fits within the theoretical framework of embodied cognition and neuroeducation, which emphasise the integration of cognitive, emotional and bodily processes in learning (Porges, 2011; Immordino-Yang, 2016; Fischer, Goswami & Geake, 2010). Qualitative analysis allows for a deeper exploration of the processes through which these changes occurred. The perception of the environment as ‘more welcoming’ and ‘less stressful’ suggests that environmental and multisensory modifications had a direct impact on the quality of daily experience. This finding is consistent with studies highlighting the influence of the physical conditions of the environment on cognitive and emotional functioning (Barrett et al., 2015). A particularly significant aspect concerns the development of emotional awareness. The students demonstrated a greater ability to recognise and manage their own internal states, indicating a change in processes

as well as in outcomes. This aspect appears crucial during pre-adolescence, a phase characterised by the progressive development of socio-emotional skills (Eccles & Roeser, 2011). The improvement in peer relationships, which emerged in the focus groups, can be interpreted in the light of social interdependence theory (Johnson & Johnson, 2009), according to which cooperative and supportive contexts promote both individual well-being and collective functioning. In this sense, the intervention appears to have fostered more positive group dynamics, contributing to the development of a shared sense of belonging. Teachers' perceptions offer further insights. The use of the dashboard and environmental feedback fostered greater sensitivity to classroom cues and a more flexible management of time and activities. This finding appears particularly relevant in the debate on educational innovation, suggesting that technology can function as a tool to support teaching professionalism, rather than as a substitute (Selwyn, 2019; Luckin et al., 2016). From this perspective, one of the study's most significant contributions concerns the role of technology as an educational mediator. The integration of physiological data, environmental sensors and interpretative dashboards has made it possible to move beyond a static conception of teaching, introducing a dynamic and responsive dimension. This finding fits within the framework of learning analytics and smart learning environments, which highlight the value of data in supporting informed pedagogical decisions (Ifenthaler & Yau, 2020). From a theoretical perspective, the findings help to reinforce a systemic view of learning, in which cognitive, emotional and physical dimensions are deeply interconnected. Well-being thus emerges not as a secondary outcome, but as a structural condition for meaningful learning. Despite the promising results, the study has some limitations. Firstly, the relatively short duration of the intervention does not allow for an assessment of the stability of the effects in the long term. Secondly, the sample, limited to a single school context, reduces the generalisability of the results. Furthermore, a possible Hawthorne effect or a residual influence of the novelty effect cannot be ruled out (Clark, 1983).Finally, the interpretation of physiological data, whilst supported by

the literature, requires caution, as such indicators may be influenced by contextual variables that cannot be fully controlled (Shaffer & Ginsberg, 2017). In light of these limitations, future research should adopt longitudinal designs and include larger and more diverse samples. A further development concerns the integration of artificial intelligence systems for the analysis of multimodal data, accompanied by in-depth ethical consideration. Overall, the results suggest that the integration of technology, environment and pedagogy represents a promising direction for the design of more adaptive, inclusive and well-being-oriented educational contexts.

Conclusions

This study makes a significant empirical contribution to our understanding of the role of hybrid and emotionally aware learning environments in contemporary school settings. The integration of quantitative, physiological and qualitative data allows us to state, with a high degree of reliability, that the intervention produced positive effects on individual, relational and systemic dimensions. One of the most significant elements concerns the integrated nature of the intervention. The results indicate that the change is not attributable to a single component, but to the synergistic interaction between technology, environment and pedagogical practices. From this perspective, technology emerges as a mediator that makes implicit dynamics visible and supports more informed decision-making processes. Particularly relevant is the role of the teacher, who acts as a central figure in mediating between data, context and educational action. The use of the dashboard helped to strengthen teachers' observational and regulatory capacities, confirming that technological innovation can enhance, rather than replace, teaching professionalism (Luckin et al., 2016; Selwyn, 2019). From a theoretical perspective, the study supports a conception of learning as a multidimensional, embodied and relational process. Well-being emerges as a structural condition for the activation of effective cognitive and emotional processes, in line with the perspectives of embodied cognition and socio-emotional learning. In practical terms, the results

suggest that it is possible to design innovative educational environments that are both technologically advanced and pedagogically sustainable. The intervention did not require a break with existing practices, but rather fostered their evolution towards more adaptive and mindful forms, a crucial element in terms of transferability. However, the conclusions must be interpreted in light of the study's limitations, particularly the duration of the intervention and the specificity of the context. It is therefore necessary to continue the research through longitudinal and comparative studies. Looking ahead, the evolution of these environments could benefit from integration with increasingly sophisticated artificial intelligence systems, provided this is accompanied by careful ethical consideration regarding data management and the transparency of decision-making processes. In conclusion, this study highlights how the design of emotionally aware learning environments represents a promising path for educational innovation. The integration of technology, environment and pedagogy opens up new possibilities for a more inclusive, adaptive and person-centred school, in which well-being is an essential prerequisite for meaningful and sustainable learning.

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