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Introduction

Neurotechnology in the classroom: Current research and future potential

Guest-edited special issue:
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The emerging development of neurotechnologies is providing new opportunities for educational research in cognitively diverse environments. It is now possible to examine mechanisms, processes and learner-teacher interactions in the natural context of the classroom through the use of different portable neurotechnologies, such as: eye-tracking, electroencephalography (EEG), electrodermal activity (EDA) or other mobile devices such as "Brain-Computer Interfaces for Education" (BCIE), or "functional near-infrared spectroscopy" (fNIRS) devices. With this development, a growing field of studies has proliferated in recent years advocating research in naturalistic classroom settings (Dahlstrom-Hakki et al., 2019; Janssen et al., 2021; Godwin et al., 2022), real-world classroom studies (Bevilacqua et al., 2019; Salazar et al., 2021; Davidesco et al., 2023; Matuk & Linn, 2023), and authentic or ecologically valid studies (Van-Atteveldt et al., 2018; Pierguidi et al., 2019; Thomas et al., 2019; Mangaroska et al., 2021).

What counts as a neurotechnology? Neurotechnology comprises a range of techniques that offer indications about the operation of the brain separate from its manifestation in the kinds of behaviour that educators typically monitor to track students' progress in learning. Its use is therefore predicated on the assumption that the way that learning is implemented in the brain will be relevant for educators (Thomas et al., 2020). These technologies might directly reflect physiological markers of brain function, such as in the brain's electrical discharges (EEG) or its oxygenated blood flow (fNIRs); they may reflect body markers of the operation of the sympathetic autonomic nervous system, often indexing emotional processes (electrodermal activity); or they may detect subtle behavioural markers reflecting attention processes or memory retrieval (eye-gaze). Together, these measures can offer a window on students' engagement in the classroom, their current knowledge, and the nature of learning as it unfolds.

There are two advantages that neurotechnology can potentially bring to the classroom. It can offer educators real-time information to guide practices, either on the current state of their students or the effectiveness of the teacher's current activities – though the technical challenge to instantly turn rich neurotechnology data into an educationally usable form renders this still perhaps a promise rather than a reality. The second advantage is that using neurotechnologies in the classroom provides greater ecologically validity to study learning and instruction in the context where it occurs, rather than the artificially controlled context of the laboratory. This means that the use of neutotechnologies in classroom engaging with the embodied sensory, emotional, and social context in which teaching and learning actually occurs.

This Special Issue is a contribution to this emerging field, compiling a variety of studies conducted in Spain, Portugal, Latin America or Taiwan, carried out with different neurotechnologies and approaches, from different perspectives, but of relevant validity to continue understanding the scope of these neurotechnologies, their applicability, or new approaches to responsible research and educational innovation in the classroom.

Introduction

The work by Serrano-Mamolar, Miguel-Alonso, Checa and Pardo-Aguilar Explora ("Towards learner performance evaluation in iVR learning environments using eye-tracking and Machine-learning") presents an experience of using eye-tracking data in an immersive Virtual Reality (iVR) learning environment as a combination in the use of neurotechnologies and basic Machine Learning techniques, through which the quality of learning conditions can be assessed and learner performance can be predicted. These are models and algorithms that must guarantee even higher levels of accuracy, but with promising results for understanding the factors and stressors that influence learning sessions.

The study by Juárez-Varón, Bellido-García and Gupta ("Analysis of stress, attention, interest, and engagement in onsite and online higher education: A neurotechnological study") presents an experiment with master's students using different types of neurotechnologies (galvanic response, electroencephalography and eye-tracking) to compare brain recordings that can measure levels of attention, interest, stress and emotional engagement in a face-to-face and an online educational context. The results showed differences indicating that brain activation levels are higher in the face-to-face context, with relevant implications for the study of attentional activation.

The work by Sáiz-Manzanares, Marticorena-Sánchez, Martín-Antón, Almeida and Carbonero-Martín ("Application and challenges of eye tracking technology in Higher Education") makes an innovative contribution in a natural classroom environment, which has been developed between Spanish and Portuguese researchers with eye-tracking neurotechnologies. The study serves to assess the functionality of this technology and to understand the challenges for teachers who intend to use eye-tracking devices, which are not only focused on knowing how to handle the technological issues, but also on acquiring skills for the analysis of the multiple data generated ("Educational Data Mining"), understanding the meaning of the different metrics to explain the learning processes in the classroom and what eye tracking is offering for the teaching improvement.

The work by García-Monge, Rodríguez-Navarro and Marbán ("Potentialities and limitations of the use of EEG devices in educational contexts") presents a study with primary school children that verifies the potential of portable electroencephalography devices for measuring cognitive and emotional processes. At the same time, it presents some limitations associated with four different EEG devices, which vary in terms of cost, ease of use, signals emitted or the usefulness of the data generated. It is a basic introductory study for educators and educational researchers who intend to explore the use of these devices in the classroom.

And the work by Hidalgo-Muñoz, Acle-Vicente, García-Pérez and Tabernero-Urbieta ("Application of neurotechnology in students with ADHD: An umbrella review") presents a review of studies that have used neurotechnologies to improve the symptomatology and favour the cognitive abilities of schoolchildren with attention deficit hyperactivity disorder, finding that neurofeedback and transcranial stimulation are the most frequently used. This review shows that studies are still in their infancy, and more studies are needed to report on the ethical requirements of their application in the classroom, the implications for the teachers using it, as well as the use of other neurotechnologies such as hyperscanning, and even on errors learned from experiments to ensure thresholds of safety and quality of the results.

All these studies and other published to date have been carried out from a cautious approach (Janssen et al., 2021; Privitera & Hao, 2022) that advances possibilities for understanding the learning brain and knowing how to offer personalized guidance, but also warns of limitations related to ethical and ecological validity. Among the potentials are the immediacy to obtain and analyse data in real time, both from teachers and students (Dikker et al., 2022), and the possibility of understanding the effects of educational interaction through inter-brain activity (Matuk & Linn, 2023; Davidesco et al., 2023). And among the limitations are the main challenges of natural research with neurotechnologies (duration of experiments, interference, stimulus failure, excessive repetition of tasks…), the limitations of handheld devices (calibration, disconnection, discomfort…), neuro-prediction (Van-Attenveld, 2018) or inference from indirect or anatomical measures, from insufficient tasks or replication problems, even in terms of device cost, from which a new trend of low-cost or affordable neuro-research has emerged (Valliappan et al., 2020; Pierguidi et al., 2019). To these considerations must also be added the ethical concerns (UNESCO, 2022) and the proposal for more specific principles on responsible research in education, ensuring that neurotechnological devices remain non-invasive, reach vulnerable schools or respect ethnic issues (Davidesco et al., 2021; Genser & Herrmann, 2022), while protecting the records generated while respecting the privacy of neurodata, especially from minors.

With the current limits, we understand that research with neurotechnologies in the classroom is an area yet un-explored, but of great interest, as demonstrated by the many contributions received for this Special Issue, in which expert reviewers have also collaborated, and we thank them for their contributions. This monograph has helped to make this innovative and crossfield visible and to understand how new technologies generate new possibilities, but also new responsibilities to reflect on the future educational agenda.

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