# Detecting Confusion in Online Learning with EEG Signals

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## 1 Introduction

Online education platforms have unlocked unprecedented access to knowledge, yet struggle to recognize when learners are lost in the moment. Confusion is often productive, but a potentially discouraging cognitive state can derail progress if it goes undetected. Researchers have shown that even a single-channel Electroencephalography (EEG) headset positioned on the forehead can capture neural signatures of confusion. Leveraging the EEG brainwave data with advanced machine learning techniques, this project proposes a predictive model to classify confusion during an online class and a time series visual analytics. With the help of signal processing and modern deep learning models, we aim to illuminate how subtle shifts in Beta, Theta, or Gamma bands show moments when students need extra support. In this project, the instructors are the primary users of the confusion visualization. The goal is to help instructors understand when students are struggling, so they can step in with support or improve how they teach that material in the future. By spotting patterns of confusion during lectures, teachers can respond more effectively, adjust their teaching style, and keep students more engaged and on track.

## 2 Background Studies

Detecting and responding to learner confusion is a critical challenge in education platforms, particularly Online Courses. Research on cognitive states during learning has established confusion as potentially productive and detrimental to educational outcomes. In 2013, D'Mello et al. demonstrated that confusion can trigger deeper cognitive engagement when properly scaffolded but leads to disengagement and frustration when persistent [1]. Neurophysiological approaches in detecting cognitive states have gained traction in educational contexts. Single-channel EEG devices can detect confusion states accurately when approaching clinical equipment and appropriate signal processing is applied. In the specific domain of MOOC-based learning, Wang et al. [2] conducted pioneering work collecting EEG data from students watching MOOC video clips, establishing a correlation between self-reported confusion and neural signatures. Building upon this foundation, Chen et al. achieved approximately 75% accuracy in predicting confusion states using traditional machine-learning approaches with handcrafted EEG features [3].

In 2016, Renosa et al. developed an artificial neural network (ANN) to classify a person's confusion level using EEG brainwave frequency data [4]. Analyzing the power spectrum of different brain signals offers insights into how confusion and cognitive workload manifest in the brain, with potential applications in education and gaming. In 2023, Ganiga et al. built a brain-wave listener for online courses that tracks students' EEG signals and flags moments of confusion in real time [5]. It blends machine-learning probability cues with Long Short-Term Memory (LSTM) to detect confusion and achieve a mean accuracy of $\sim$95.67%. Another recent study explores the key role of confusion in learning and how can be detected through brainwave (EEG) patterns during reasoning tasks [6]. By designing experiments to trigger confusion intentionally and comparing EEG signals across different emotional states, the researchers built a reliable database. They showed that machine learning models, especially Random Forests, can accurately tell when someone is confused. Their accuracy is approximately 84.43%.

Our research focuses on a time-series approach that combines visual analytics with advanced predictive modeling. We utilize the dataset collected by Wang et al. in 2013 [2], which includes EEG signals from

10 college students watching MOOC videos on topics ranging from basic algebra to quantum mechanics, with self-reported confusion ratings. This dataset provides the foundation for our investigation into the neural correlates of confusion and the development of predictive models that can identify when learners are experiencing cognitive bottlenecks.

## 3 Problem Statement

Can we accurately predict, and visually explain, when a learner becomes confused while watching MOOC videos, using only their frontal-lobe EEG signals?

## 4 Objectives

The objectives of the projects are

- A Predictive Model: Design, train, and evaluate a classification model capable of detecting confusion from EEG signals, with a focus on generalizing to unseen subjects.
- Visualization of Neural Activity Patterns: Develop comprehensive visual analytics of brainwave activity (Alpha, Beta, Gamma, Theta, Delta) and cognitive indices (e.g., attention, meditation) to identify patterns associated with confusion during cognitive tasks.

## 5 Methodology

We will follow a systematic approach to develop a subject-independent model for confusion detection using EEG signals and to visualize brainwave patterns associated with cognitive states.

**Data Collection** We are using an open-source dataset from **Kaggle**, "Confused student EEG brainwave data" [2].

**Feature Extraction** The dataset contains the signal data from an EEG set and demographic data of the students in csv files. Additionally, it contains the 10 videos that the researchers used to generate EEG the data. EEG file contains the Alpha, Beta, Gamma, Theta, Delta, attention, meditation data from the device. Along with these, for each instance, the dataset contain the predefined confusion for the video and student defined confusion. Demographic information includes age, ethnicity and gender. We will extract the frequency-domain features, such as Alpha, Beta, Gamma, Theta, and Delta and cognitive indices such as attention and meditation levels are considered to enhance interpretability.

**Model Development** The model is developed using a subject-independent approach, where training and testing are done on separate groups of participants to evaluate generalizability. We will use a neural network-based learning model LSTM for classification. Additionally, hyperparameter tuning and k-fold cross-validation will be used to optimize performance.

**Model Evaluation** To evaluate model's performance accuracy, F1-score, and confusion matrix will be considered.

**Visualization** Visualization include a time-series plots, heatmaps and bar plots to visualize EEG signal dynamics and the pattern of confusion among students during an online class.

## 6 Outcomes

By the end of the semester, we aim to:

- Develop a predictive model capable of detecting confusion from EEG data.
- Generate clear and interpretable visualizations highlighting EEG patterns.

Our long term goal includes

- Enhancing the model's accuracy and generalizability across diverse users.
- Implementing real-time confusion prediction and building an interactive dashboard for dynamic EEG visualization.

## 7 Conclusion

This project integrates advanced EEG analytics and interpretable machine learning models to deliver immediate, actionable insights into learner confusion. The outcomes promise significant improvements in online educational environments by enabling adaptive MOOC platforms to proactively respond to learners' cognitive states.

## References


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