

# Your Brain on STEM Video Lessons: Exploring Neurophysiological Patterns and Educational Engagement to Video Content

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## Abstract

The COVID-19 pandemic catalyzed a significant shift towards online learning, revealing the potential of online educational videos as an educational tool in the post-crisis era. As we venture through this evolved educational terrain, it becomes crucial to understand the effectiveness and impact educational video content has on students' engagement and performance. This research explores how different styles of educational video content on STEM (Science Technology, Engineering, and Mathematics) topics impact students' engagement and comprehension using Electroencephalography (EEG) and eye-tracking data of participants viewing the educational video. In particular, we propose a machine learning driven analysis framework to study which EEG and eye-gaze-based metrics are informative of students' engagement and attention to STEM-related educational videos and predict student-population-wide comprehension. Although still in the preliminary stages, our research endeavors to identify correlations between neurophysiological patterns and educational engagement across disciplines.

## Introduction

The COVID-19 pandemic catalyzed an unprecedented shift towards online learning as schools and universities globally pivoted to digital platforms and asynchronous online video format. Aristovnik et al. (2023) found a direct correlation between exposure to online video content during the pandemic and overall student satisfaction with their university. The efficiency of online learning demonstrated during the pandemic suggests a lasting integration of digital education tools beyond the crisis. However, as we navigate this new educational landscape, there is a need to study the effectiveness and impact educational video content has on student performance.

Among all educational lecture topics, materials of Science, Technology, Engineering, and Mathematics (STEM) have a broader impact on student success. In particular, Chen and Chen (2021), in a 16-week integrated-instruction

research study, found that the STEM inquiry method enhanced students' scientific activity, inquiry ability, and creative thinking, leading to improved learning attitudes and problem-solving skills. Therefore, there is a need to study how STEM-related videos engage students of different backgrounds and facilitate their understanding of the materials.

Neurophysiological (i.e., Electroencephalography – EEG) and eye-tracking measurements are valuable for studying user's engagement, attention, comprehension, emotions, and cognitive load during video viewing. For example, Christoforou et al. (2017) used EEG and eye-gaze data to measure participants' levels of engagement when viewing a selection of movie trailers. In particular, the authors used a machine learning approach to calculate a cognitive congruency metric on selected EEG frequency bands. They used those to predict the population-wide user preferences for those movies. Similarly, Christoforou et al. (2017) calculated an attentional-asynchrony metric from eye-gaze data, serving as a tool for measuring how consistently viewers focused their attention during segments of the movie trailers. Attentional asynchrony combined with Cognitive congruency metrics improves the predictability of population-wide user preferences. Neural congruency, an EEG-based metric, has been shown to predict participants' emotions while listening to music videos (Christoforou et al., 2021). In an earlier study, Christoforou et al. (2014) showed that attentional asynchrony of users watching video advertisements predicts the advertisement's success.

In the context of educational videos, Madsen et al. (2021) demonstrated a significant correlation between synchronized eye movements and test scores in online video education. Moreover, Ni et al. (2020) explored an EEG-based attention metric, calculated by the chip of the Mind-wave EEG device, showing a significant difference in attention levels between active and reflective learners when viewing video media, suggesting that students' background and learning style impact the benefit they can get from online video content. Therefore, more studies are needed

on how educational video content style impacts the attention and engagement level of students from different backgrounds or learning styles.

In this work, we aim to design a study to explore how EEG-based neural congruency metrics and eye-gaze-based attention asynchrony predict students' performance on STEM topics presented via different video content styles. Moreover, we will examine differences across these metrics between learners from STEM and non-STEM backgrounds. At this preliminary stage of our research, we briefly discuss our experiment design, and analysis methodology.

## Methodology Plan

**Educational Video Experiment Design:** For our experiment, 100 university students (half from STEM majors) will watch eight videos on four STEM topics (Support Vector Machines, Bayes Theorem, Algorithms and Data Structures, and the Fourier Transform). Each topic is introduced in two videos - one introductory and a second that covers the topic in more depth. Video duration varies between 15-20 minutes. After each video viewing, students answer two questions on the subject they watched. Twenty of the participants will perform the experiment while their EEG and eye tracking data are collected, while for 80 of the participants we will only collect performance information to the on-screen questions to estimate the population-wide test scores. The experiment was designed using the OpenSesame experiment builder software using custom python code.

**Data Collection:** Three data modalities are collected during the experiment to measure a participant's level of engagement and material comprehension. In particular, we record the participants' visual attention during the video using an eye tracker. Eye-gaze data is collected at a 30Hz sampling frequency. To ensure correct alignment between gaze and screen coordinates, a 9-point calibration is performed before the video presentation. EEG data is simultaneously recorded using a g.nautilus active electrode EEG device from g.tec. EEG data are samples at a 250Hz sampling rate. To align the EEG data stream to the video stream, we used a LabJack U3-HV data acquisition card to send trigger events at the onset of every second of video viewing. Similarly, timestamp trigger events are sent to the eye-tracking stream. These trigger events are used during analysis to synchronize two data streams to the video data stream. Participants' answers to the on-screen questions are also recorded in a comma-separated file.

**EEG preprocessing:** EEG preprocessing is performed separately on the recordings of each participant. First, EEG

data are segmented between the starting time and ending time of each video, using the trigger channel information in the EEG signals. Subsequently, all channels are re-referenced to the average channel. A 0.5 Hz high pass filter followed by a 60Hz notch-filter is applied to remove DC drifts and power line noise interference. Finally, the pre-processed EEG segment is epoched into 5-second EEG trials, onset at one-second intervals. After preprocessing, the EEG activity of each video segment and each participant is represented by a set of EEG trials with a distinct onset timestamp  $EEG_{s,v} = \{X_t^{(eeg)} \in \mathbb{R}^{D \times T} \forall t < N\}$ , where  $s$  the participant index,  $v$  the video index,  $t$  the trials onset index in seconds,  $D$  the number of channels,  $T$  the trial duration, and  $N$  the number of trials. Similarly, eye-tracking data are segmented eye-gaze trials  $EYE_{s,v} = \{X_t^{eye} \in \mathbb{R}^{2 \times T} \forall t < N\}$ , where the two rows of  $X_t^{eye}$  correspond to the x and y screen coordinates of the gaze.

**EEG and Eye-gaze Engagement metrics:** We aim to identify neural components in the EEG signals elicited in response to educational video viewing that maximizes the neural congruency across participants in the STEM group. We hypothesize that the congruency of the neural signals over time and across participants and video will serve as markers of users' cognitive engagement with the educational content. We will extract the neural components by adapting the method proposed by (Christoforou et al., 2023) to consider distinct frequency bands (i.e., high-gamma activity) that are associated with viewer engagement (Christoforou et al., 2017). Similarly, we plan to quantify participants' visual attention using the attentional asynchrony score proposed by (Christoforou et al., 2014). Therefore, for each temporal trial pair  $(X_t^{eeg}, X_t^{eye})$ , we plan to extract a feature vector  $Z_t \in \mathbb{R}^{F+1}$  that encapsulates the neural congruency score modulations on  $F$  frequency bands and the attentional asynchrony score of the trial. A simple regression model will be used to evaluate the ability of the feature vectors to predict student population-wide comprehension of each video and group.

## Summary and Future Work

In this preliminary stage of our work, we identify the need and propose an analysis framework to study which EEG and eye-gaze-based metrics are informative of students' engagement and attention to STEM-related educational videos and predict student-population-wide comprehension. In the next stage of our research, we plan to finalize the data collection procedure, evaluate the predictive power of the proposed metrics, and analyze differences in engagement and attention levels between STEM and non-STEM majors students.

## References

- Aristovnik, A.; Karampelas, K.; Umek, L.; and Ravšelj, D. 2023. Impact of the COVID-19 pandemic on online learning in higher education: A bibliometric analysis. In *Front. Educ.*, 8:1225834. <https://doi.org/10.3389/feduc.2023.1225834>
- Chen, K., and Chen, C. 2021. Effects of STEM Inquiry Method on Learning Attitude and Creativity. In *Eurasia Journal of Mathematics, Science and Technology Education*, 17(11): em2031.
- Christoforou, C.; Christou-Champi, S; Constantinidou, F.; and Theodorou, M. 2015. From the eyes and the heart: a novel eye-gaze metric that predicts video preferences of a large audience. In *Front. In Psychology*. <https://doi.org/10.3389/fpsyg.2015.00579>
- Christoforou, C.; Papadopoulos, T.C.; Constantinidou, F.; and Theodorou, M. 2017. Your Brain on the Movies: A Computational Approach for Predicting Box-office Performance from Viewer's Brain Responses to Movie Trailers. In *Front. Neuroinform.*, 11:72. <https://doi.org/10.3389/fninf.2017.00072>
- Christoforou C.; Theodorou, M. 2021. Towards EEG based emotion recognition during video viewing: Neural congruency explains User's Emotion experiences in music videos. *The International FLAIRS Conference Proceedings* 34. <https://doi.org/10.32473/flairs.v34i1.128458>
- Christoforou C.; Papadopoulos, T.C.; Theodorou, M. 2023a. Regularized Neural-congruency on Spoonerism: Towards exploring the neural-underpinnings of reading disorders on phonological processing tasks. *The International FLAIRS Conference Proceedings* 36. <https://doi.org/10.32473/flairs.36.133038>
- Madsen, J.; Júlio, S.U.; Gucik, P.J.; Steinberg, R.; Parra, L.C. 2021. Synchronized eye movements predict test scores in online video education. In *Proc. Natl. Acad. Sci. U.S.A.*, 118:e2016980118. <https://doi.org/10.1073/pnas.2016980118>
- Ni, D.; Wang, S.; and Liu, G. 2020. The EEG-based attention analysis in Multimedia M-learning. In *Computational and Mathematical Methods in Medicine*, 2020:1–10. doi: 10.1155/2020/4837291.