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Research paper

Investigation of the interaction of teacher candidates' executive function skills with emotions in computer simulation environment

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ABSTRACT

The study investigates the interaction between executive functions and affect transitions in a computer simulation-based teaching task. Pre-service teachers from a state university participated and data were collected using EEG, EDA and facial expression analysis. The collected data were analyzed using event-related oscillations, sequential pattern mining and Wilcoxon Signed Ranks tests. The results show that pre-service teachers tend to use correct interventions when they are happy, but incorrect interventions when they are surprised or angry. Executive functions, especially working memory, perform better under negative emotions than under neutral conditions. The results highlight the importance of understanding emotional influences on teaching interventions.

1. Introduction

Teaching is a dynamic and complex process in which cognitive and emotional processes play active and intense roles (Pekrun & Linnenbrink-Garcia, 2014; Rodriguez, 2013). In fact, cognitive and emotional processes are recognized as intertwined structures that mutually influence each other (Forgas & East, 2008). Furthermore, it is emphasised that emotion constitutes one of the most crucial elements in the integration of learning experiences across a range of contexts, including formal, informal, personal and social learning environments (Graesser, 2020). Throughout the teaching process, teachers' cognitive scaffolding and teaching strategies are interwoven with emotional bonds (Woods & Jeffrey, 1996). As a result, all cognitive factors related to teaching, such as how teaching is planned (Hargreaves, 1998), the choice of teaching strategies (Bach & Hagenauer, 2022; Burić & Frenzel, 2023), and the persist in teaching (Audrin & Hascoët, 2024) are not independent of emotions. Additionally, this relationship is reciprocal; emotional states impact the use of cognitive skills, while cognitive capacity affects the categorization, duration, and intensity of experienced emotions (Brosch et al., 2013).

Over the past two decades, there has been substantial research exploring the relationship between executive function (EF) skills and emotions in the educational context. EF skills encompass a range of cognitive abilities that enable individuals to sustain attention, engage in reasoning, problem-solving, reflection on past experiences, and plan for the future (Zelazo et al., 2017). Executive function (EF) is defined as a set of attention regulation skills that includes conscious, goal-oriented problem-solving abilities (Kamkar & Morton, 2017; Zelazo et al., 2017). Teachers utilize EF skills in a multitude of tasks, including time management, classroom organisation, planning, flexible thinking, controlling, and remembering students' development (Manowaluilou, 2021). It is therefore recommended that EF should be a key consideration in teacher training programmes and studies in this field (Corcoran & O'Flaherty, 2017).

The impact of emotions, distinct from anxiety, on cognitive and motivational variables in educational settings has garnered attention since the 1990s (Çağlar-Özhan & Altun, 2019). Furthermore, although there has been an increase in studies on teacher emotions, it is highlighted that the emotions of pre-service teachers have been largely overlooked (Ji et al., 2022). However, pre-service teachers experience a plethora of positive and negative emotions, particularly during the teaching practicum, which is the phase in which they learn to teach (Hascher & Waber, 2020). This situation has the potential to impact professional development (Bach & Hagenauer, 2022). Furthermore, it is highlighted that pre-service teachers are susceptible to developing burnout in their professional careers and that they encounter stressors during the teaching process (Hoferichter & Jentsch, 2024).

The emphasis in the literature on the interplay of cognitive and

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emotional factors and the understanding that teaching involves the complex interplay of these factors were taken into account in the current study. The purpose of this study was to examine the effect of the interaction between EF skills, which encompass understanding and controlling cognitive processes and are considered fundamental competencies for pre-service teachers, and their emotions on teaching task performance.

1.1. Literature review

Emotion is a multifaceted construct encompassing subjective valence and arousal dimensions directed toward a target, resulting in behavioral and physiological changes (Kleinginna & Kleinginna, 1981). Research on teacher emotions has largely focused on describing their in-class emotions (Stavroulia et al., 2019), identifying the antecedents of these emotions (Bach & Hagenauer, 2022; Junker et al., 2021), and examining their consequences (Bach & Hagenauer, 2022). Studies on the antecedents of teacher emotions have explored classroom dynamics, such as the anticipation of classroom stimuli (Park & Ryu, 2019) and student engagement (Bach & Hagenauer, 2022). Broader structural factors, such as school climate and the role of teaching advisors, also significantly shape teacher emotions (Yang, 2019). Moreover, motivational factors like teachers' self-efficacy have been identified as critical determinants of emotional responses (Bach & Hagenauer, 2022). Low student engagement and teacher-centered activities have been recognized as key predictors of negative emotions in teachers (Junker et al., 2021). Conversely, environments supporting in-class activities, such as virtual reality (VR), have been shown to reduce teachers' anxiety and stress (Stavroulia et al., 2019). Importantly, VR and simulation design features can also trigger positive or neutral emotions (Park & Ryu, 2019). Findings indicate that as motivational factors like self-efficacy increase, the incidence of anger diminishes, while the prevalence of joy rises (Bach & Hagenauer, 2022). At the same time, teachers' emotions significantly influence their instructional strategies and classroom management approaches (Bach & Hagenauer, 2022). This highlights how motivational and environmental factors affect teacher emotions, which, in turn, shape teaching skills in the classroom.

Despite this, the interplay between teachers' cognitive processes—closely linked to emotions—and their emotional experiences remains underexplored in the literature. Cognitive factors are crucial in shaping the intensity, duration, and nature of experienced emotions, while emotions influence the use of cognitive skills (Clark & Isen, 1982; Plancher et al., 2019). One such cognitive factor, executive function (EF), plays a vital role in teachers' ability to respond to the dynamic attentional demands of classroom interactions, regulate emotional responses to classroom events, and solve problems flexibly (Hiver et al., 2021). EF is defined as a set of attentional regulation skills (Kamkar & Morton, 2017; Zelazo et al., 2017), encompassing components such as inhibition, cognitive flexibility, and working memory updating (Gijselaers et al., 2017; Zelazo et al., 2017).

Inhibitory control refers to suppressing or ignoring distractions and the actions that follow (Miyake et al., 2000). Cognitive flexibility involves adapting to unexpected situations and devising new and alternative solutions (Canas et al., 2003). Working memory enables individuals to hold and manipulate information or ideas in a coherent manner (Baddeley, 1992). Evidence suggests that EF, comprising these components, declines over time during teacher education (Corcoran & O'Flaherty, 2017). However, pre-service teachers with strong EF skills tend to exhibit better self-regulation, collaborate more effectively with schoolteachers, design lesson plans efficiently, manage classrooms competently, and demonstrate greater overall progress as student teachers (Manowaluilou, 2021). Therefore, understanding how this critical cognitive factor interacts with emotions and how these interactions affect teaching performance is essential.

Alongside understanding the cognitive-emotional interplay, addressing the methodological limitations in studying teachers' emotions is equally important. Some studies have sought to identify emotions through biophysiological data, such as electroencephalograms (EEGs) and heart rate measurements (Stavroulia et al., 2019), or physical data, including facial expressions (Park & Ryu, 2019), during teaching tasks in simulated environments. However, emotions are often assessed post-task through self-report methods (Bach & Hagenauer, 2022; Junker et al., 2021; Yang, 2019). Theoretical frameworks indicate that emotions are holistic constructs encompassing physical, neurological, and cognitive dimensions (Jones, 2020; Smith et al., 2019), leading to variability in their definition and measurement. Beyond self-reports, emotions can be identified through physical and physiological signals, such as facial expressions, gestures, and speech.

Ekman's (1993) Facial Action Coding System (FACS) is widely used to classify emotions based on facial expressions. Ekman (1970) posited that similar emotions exhibit consistent psychological and physical patterns across individuals. While basic emotions are universal, their triggers are culturally specific (Ekman, 1970). According to Ekman and Friesen (1971), six basic emotions—happiness, sadness, disgust, surprise, fear, and anger—constitute the foundation, with other emotions resulting from their combinations. The FACS system manually codes movements or positions of facial muscles, such as eyebrow raising, eyebrow proximity, and upper lip positioning (Ekman & Friesen, 1971). Given the time-intensive nature of manual coding, modern computer software leverages FACS for automated emotion detection (Wang et al., 2022). Examples include Emotient, iMotions, SkyBiometry, and Affect Lab, which can identify basic emotions and some cognitive states.

Similarly, EF evaluation is conducted through performance-based tasks, scales, and physiological data analysis. In this study, pre-service teachers' EF skills were assessed using Event-Related Oscillations (EROs). According to the theory of oscillatory neural populations, neurons exhibit oscillatory activity linked to specific functions (Karakaş et al., 2000). These oscillatory activities underpin the brain's parallel functioning (Başar, 2012). Oscillations generate event-related potentials (ERPs) in response to stimuli (Yordanova & Kolev, 1998), with different frequency bands—delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–25 Hz), and gamma (25–50 Hz)—serving distinct cognitive, affective, and motor functions (Başar, 1999).

1.2. Present study

A scoping review of the existing literature reveals that teachers experience a wide range of emotions in both traditional classroom settings and digital environments designed to simulate classroom dynamics. While various factors influencing teachers' emotions have been explored, the interaction between teachers' emotions and executive function—a critical cognitive skill—remains unclear. Effective classroom management requires teachers to utilize executive function skills, such as adapting flexibly to sudden and unpredictable changes, selecting appropriate responses in new contexts, and suppressing automatic or impulsive reactions. Since teachers often lack the freedom to leave the classroom in disruptive situations, those who can maintain cognitive flexibility and inhibit impulsive responses are more likely to experience positive emotions and enhanced well-being (Patrawala, 2018).

However, methods used to measure these emotions are primarily based on objective or self-reported data, with the latter being a predominant approach. A significant limitation in the research on teacher emotions lies in the reliance on self-reported data collected after instruction rather than during real-time implementation. This delayed data collection can diminish the accuracy of reported emotional intensity and lead to potential misrepresentation of the impact emotions have on instructional performance (Taylor et al., 2020). Addressing this gap by integrating real-time data collection methods could provide deeper insights into the dynamic interaction between teachers' emotions and their executive function skills (Taylor et al., 2020).

On the other hand, given the dynamic nature of educational environments, scholars suggest that perceptual and cognitive processes should be investigated in settings as close to reality as possible, employing natural stimuli, and exploring non-linear relationships between variables (Dmochowski et al., 2012; Lankinen et al., 2014). However, a multitude of factors can influence the emotional state of teachers in the classroom. To illustrate, while students' positive engagement is a predictor of teachers' positive emotions (Li et al., 2024), teachers may experience a shift in emotional state depending on the type of teaching task (Gómez-Chacón & Marbán, 2024) and the lesson's temporal context (Ji et al., 2022).

In light of these considerations and the limitations, the research questions were addressed through the use of a simulation task that closely resembled real-world classroom settings with an objective method of measurement. In this way, the potential for a multitude of stimuli to arise in the context of a real classroom was reduced, allowing for a focused examination of the executive function and emotion interaction related to the instructional task within the scope of the research. To address the objectives, two primary research questions were investigated.

1. What is the impact of the pre-service teachers' emotions on instructional task performance concerning the components of executive function (EF) skills (repetitive condition-changing condition)?
2. What is the influence of pre-service teachers' emotions on event-related oscillations, reflecting EF skill components such as working memory, cognitive flexibility, and inhibitory control, in a simulation-based teaching task?

The objective data that can be yielded from focusing directly on the interaction of teacher emotions with executive functions in a simulation task that closely emulates real-world conditions is expected to inform the design of essential intervention methods. The simultaneous definition of emotions and executive functions through the use of multiple and objective data in this study may contribute to the interdisciplinary literature on teacher education. The evaluation of both the antecedents and consequences of teacher emotions in the context of cognitive skills will provide valuable input for the design of computer-aided systems tailored for teacher training. Such systems can be presented to those undertaking initial teacher training as an additional resource to supplement their existing education.

2. Method

2.1. Participant

The study group consisted of pre-service teachers (n = 43) studying in the Department of Computer Education and Instructional Technologies at a state university and students who graduated from the same department but had no previous teaching experience (n = 2). In this study, the sample selection criteria were defined as having taken a classroom management course and having no previous teaching experience at K-12 schools in their field. Since cognitive flexibility, one of the components of executive function, is known to be closely related to the experience (Ritter et al., 2012), the criterion of no teaching experience was included in the sample selection. As individuals with and without teaching experience are likely to react differently to misbehaviour in the simulated virtual classroom due to their different levels of experience, this situation, which was thought to affect the results within the research problems of this study, was excluded. Therefore, all pre-service teachers who met these criteria were included in the study. According to the demographic information form applied to the study group, all of the participants were healthy individuals who had not previously received psychiatric or neurological diagnoses, had not used such drugs, had no visual problems, and reported that they slept between 6 and 8 h on average before the application.

2.2. Simulation Task-SimInClass

SimInClass is a virtual reality based commercial classroom simulation that includes all the components of a classroom in a three-dimensional modelled virtual environment. It includes students whose behaviour is modelled according to the OCEAN five factor personality model (McCrae & John, 1992), students' undesirable behaviours, methods of dealing with these behaviours, lesson plan, creation of lesson content, smart boards, tablets in a technological classroom and other components. This simulation, created in a responsive structure, can be used via computers, tablets and smartphones. In the three-dimensional virtual classroom, students are given the opportunity to practice with scenarios of different levels of difficulty, supported by artificial intelligence. A usability study of SimInClass, which has been the subject of many scientific studies since its development, was conducted by Dogan and colleagues (2018). In the study, which was conducted with 39 teacher candidates, authentic tasks of 60 min were presented to the participants. The results showed that the simulation interface was understandable and easy to use. It was found that possible limitations are eliminated by using high resolution, and high performance computers. SimInClass has been developed by SimSoft. In this study, the general structure of the simulation was rearranged without changing the interface, only the simulation rules were rearranged to require executive function (EF) skills. (see Fig. 1). The computer simulation prepared for this study incorporates intricate scenarios, including planning, time management, and the utilisation of appropriate methods for addressing misbehaviour. Consequently, it can be posited that the simulation possesses a multitude of characteristics that will necessitate the deployment of executive functions by pre-service teachers, and a context that is conducive to the investigation of the research questions has been established. The primary objective of this task was to assess participants' ability to provide appropriate responses to both repetitive and changing conditions exhibited by virtual students in the simulated classroom.

For instance, pre-service teachers were expected to remind a student who damages classroom equipment about the established classroom rules. Similarly, they were required to respond appropriately to various other conditions, such as a student playing with a mobile phone, sleeping, or whispering with a friend, all of which warranted the same type of intervention. Each of these conditions was presented to the participants five times consecutively, and they were asked to apply the suitable intervention method accordingly. Following the five repeated situations, the virtual students' behavior changed, presenting a new type of unwanted behavior that required different intervention strategies. For example, an undesirable behavior like harming a friend might be exhibited, demanding an updated approach and a shift in the intervention method. In this scenario, pre-service teachers were expected to adapt their existing knowledge and modify their intervention strategies accordingly.

Furthermore, the simulation task included situations that required teacher-student interaction but did not necessitate immediate intervention. For instance, the pre-service teacher was asked to perform tasks such as distributing worksheets or utilizing technology knowledge to open a presentation on the smart board for explaining a subject. Under these circumstances, the pre-service teacher was expected to temporarily withhold the intervention methods he/she intended to apply and subsequently execute them as needed. These scenarios, along with various undesirable behaviors, were integrated into a 20-min simulation environment, encompassing 25 different case studies and five distinct conditions. The case studies were selected from scenarios featured in SiminClass, an existing classroom simulation, and were strategically arranged to elicit the application of executive function (EF) skills. In this study, task performance was regarded as an indicator of the accuracy of responses to repetitive and changing conditions presented in the simulation task.

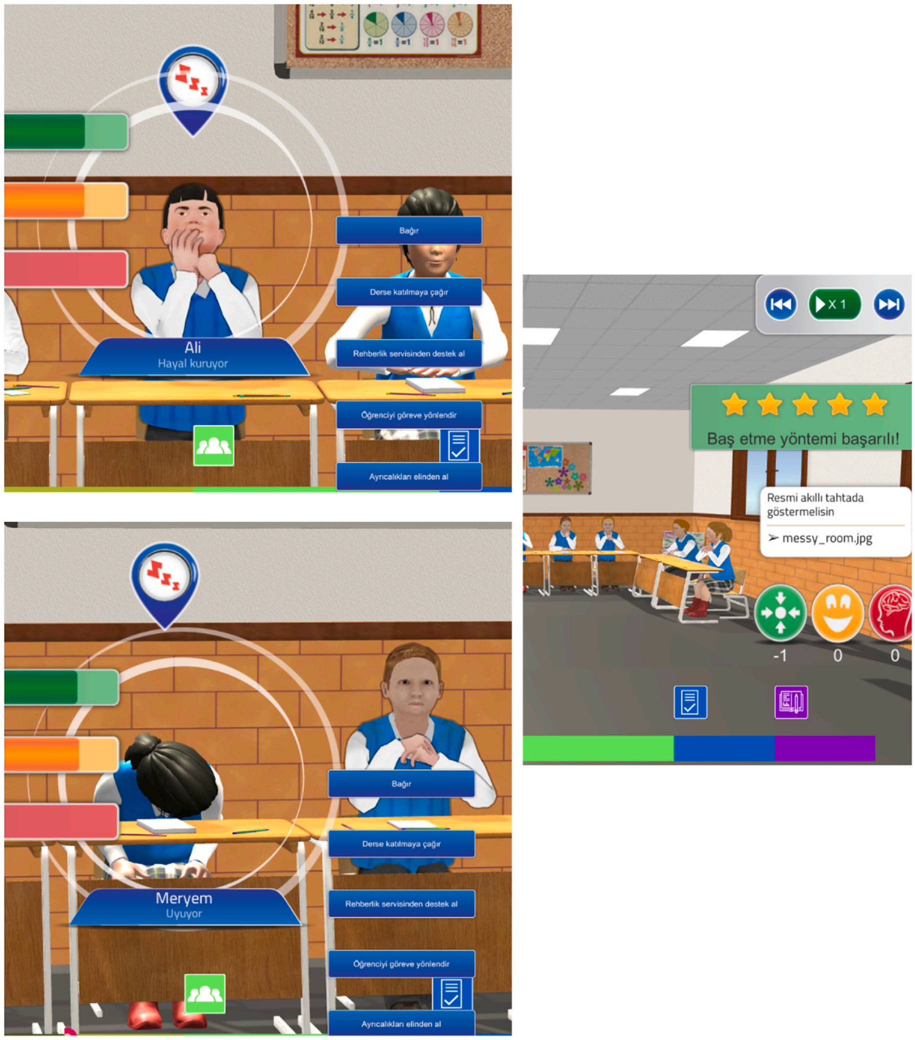

Fig. 1. Screenshots of the simulation task.

2.3. Data collecting tools

The study investigated the interactions among several variables, including the participants' emotional states, executive function (EF) skills as a cognitive individual difference, and their performance in a virtual classroom simulation task. To capture these interactions comprehensively, physical (facial expressions), physiological (electrodermal activity - EDA), electrical activity in the cortex (EEG), and behavioral data (log records) were collected simultaneously. The iMotions software, capable of capturing and documenting data from these three sources simultaneously, and the data collection tools illustrated in Fig. 2 were employed in the study.

For participant emotions, one of the variables in the study, the iMotions software was utilized to generate values for seven basic emotions using data from EDA (Electrodermal Activity) and facial expressions captured by the camera. The arousal dimension of the emotion was

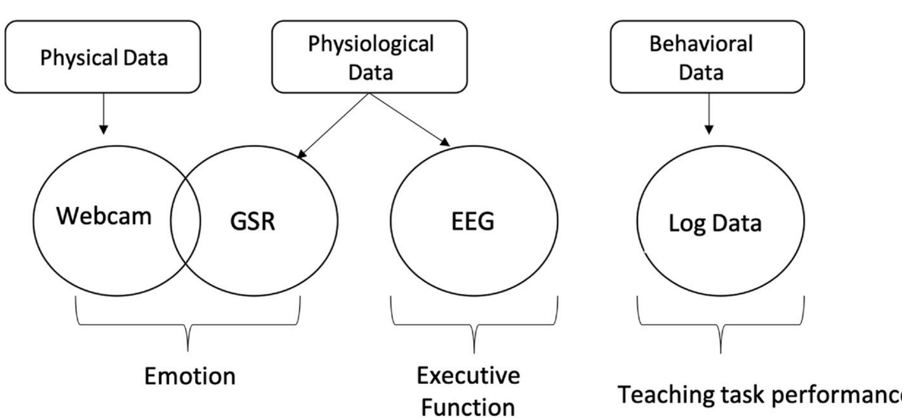

Fig. 2. Data sources.

calculated using EDA, while facial expression movements and muscle combinations captured by the camera were used to generate values for seven emotional states. Additionally, data on participants' performance in the simulation task were obtained from log records. The EF skill was determined through frequency-based analysis of EEG data.

Electrodermal Activity (EDA) measures heat and electrical changes in the skin resulting from sweat and nerve activity. EDA is closely related to the arousal-vitality level of the sympathetic nervous system. Increased arousal indicates emotions such as excitement, alertness, anxiety, fear, and anger (Blikstein et al., 2017). The study used a wireless Shimmer3 GSR with Silver (Ag)/Silver Chloride (AgCl) electrodes, capable of capturing 256 samples per second. As different emotional states can cause similar activations, data from physical sources were also obtained, as recommended in the literature (Shu et al., 2018). The data collected from EDA were interpreted by the iMotions software to represent the arousal dimension of emotions. Facial expressions data were also used to determine emotions.

Facial muscle movements and expressions of the participants were recorded with a camera. The data were labelled using the Affectiva analysis kit through the iMotions 7.1 software. Affectiva is a commercial analytics kit developed by the MIT Media Lab (Korosec, 2021). Affectiva's AI uses deep learning, computer vision, language science and real-world data to understand human emotions and cognitive states. Affectiva has analyzed over 10 million faces from around the world, making its emotion database one of the largest (MIT Media Lab, 2021). Affectiva works on the basis of the Facial Action Coding System (FACS) introduced by Ekman and his colleagues (Ekman et al., 2007). Emotion labelling by this software involves three steps: (1) capturing and framing the participant's face, (2) capturing the coordinates of the eyes, eyebrows, mouth and nose and matching the participant's face with the face models introduced in the software, and (3) analysing the perceived features through a classification algorithm and assigning emotion labels. Affectiva generates evidence scores for seven discrete emotions from different types of data sources, including head orientation (yaw, pitch, roll), interocular distance, and 34 facial landmarks (iMotions, 2021). Evidence scores are the logarithmic probability of a facial expression occurring in that frame. For example, if the software labels a frame as happy, it controls the activation status of action unit 6 (cheek-raising, orbicularis oculi) and action unit 12 (lip-curving, zygomaticus major) based on FACS (Frenzel et al., 2024).

In this study, the threshold was set to ensure that the probability of an emotion was .70 and above when labelling emotions. In addition, as part of the data diversification, the arousal data obtained from the GSR, which is an indicator of the intensity of the emotion, was examined by an expert on the timeline and low intensity emotions were eliminated. This increased sensitivity. In a study to measure the sensitivity of iMotions Facial Expression Analysis (Frenzel et al., 2024), the threshold was set at .80 and the frames labelled by the software were also labelled by human coders. The software and human coders were found to be in agreement between 84% and 97%, and this was seen as important evidence for the validity of the measurement tool. Affectiva and iMotions have also been validated with many empirical studies. Affectiva's emotion recognition performance was found to correlate highly with facial electromyography (EMG), a physiological signal (Kulke et al., 2020).

Electroencephalogram (EEG) is capable of observing electrical processes occurring near the brain surface and measuring these activations (Bayazıt, 2018). In this study, a wireless wearable Neuro Enobio EEG with eight channels, Ag/AgCl electrodes, 500 samples per second, and a bandwidth in the range of 0–125 Hz was used. The electrodes were positioned in the frontal region, as recommended in the literature, to measure EF skill (Irak et al., 2014). Frontal (Fp1, Fp2, Fz, Fpz), medial frontal (F3, F4), and lateral frontal (F7, F8) electrode sites were selected. The left mastoid served as the reference and an ear electrode was used.

2.3.1. Process

The data collection process was conducted simultaneously with the application. Each participant underwent the data collection process one by one. The process, which took approximately 45 min for each participant.

The implementation process began with informing the participants about the study. Subsequently, information regarding the demographic characteristics and health status of the pre-service teachers who volunteered for the study was collected. Before commencing the data collection process, the sensors used were calibrated. Data with a quality below 70% were excluded from the study. To facilitate preliminary analyses, data were collected to establish baseline levels for the participants. Additionally, a practice session was conducted to familiarize the participants with the virtual environment and sensors before proceeding to the actual implementation phase of the simulation task. The familiarization session lasted 10 min and involved providing the participants with information about the tasks in the environment and the actions they needed to take. Participants applied appropriate intervention methods to address unwanted behaviors similar to those encountered during the practice. In this process, any questions related to technical aspects of the application and the process were addressed. The actual implementation phase then commenced, with each participant performing the simulation task described in the materials section.

2.4. Data analysis

In the study, data were analyzed using lag analysis, a sequential pattern mining method, for investigating the relationship between the temporal change of pre-service teachers' emotions according to stimulus type and teaching task performance. The effect of mood differences on frequency bands reflecting working memory and cognitive flexibility was analyzed through event-related oscillations.

Lag Analysis: Lag analysis involves extracting sequential models of patterns of actions according to events or time and testing the significance of events occurring sequentially (Bakeman & Gottman, 1997). It is recommended, particularly for analyzing short sequence sequential data (Bosch & Paquette, 2021). For this study, a transition frequency matrix was created, encompassing 185 emotion-behavior-consequence pattern codes. Using the transition frequency matrix, the z value was calculated to determine the statistical significance of each transition. Transitions with a z value greater than 1.96 were considered to reach a statistically significant level ($p < .05$) (Bakeman & Gottman, 1997). Microsoft Excel was used to calculate the frequency matrix and z value.

Event-Related Oscillations: Event-related oscillations were analyzed to examine the effect of individuals' emotional states on frequency bands specific to components reflecting EF skills. This analysis involved investigating frequency-specific oscillations of sensory, motor, and cognitive processes related to the task through power dynamics. In this study, analyses were performed using alpha frequency (Sargent et al., 2021), beta frequency (Picazio et al., 2014) and gamma frequency (Abhang et al., 2016), which are known to be associated with EF skills. The EEGLAB software was used for this procedure. A series of operations recommended by the Swartz Center for Computational Neuroscience [SCCN], the provider of EEGLAB, were applied for the preliminary analysis of the data (SCCN, 2024). The first step was to prepare the EEG data set in a format suitable for EEGLAB. Noise was reduced by applying a 1 Hz high-pass, 50 Hz low-pass FIR (Finite Impulse Response) filter to the data (3) only artefacts related to muscle and eye movements were removed using the most commonly used Independent Component Analysis algorithm, "Run ICA" (4) epochs were removed according to stimuli (unwanted behaviour in repetitive and changing conditions).

After preliminary analyses, the means of the responses following each stimulus/episode in the classroom simulation task were calculated for each frequency band. Statistical analyses using Wilcoxon Signed Ranks tests were conducted to determine whether these mean values differed significantly for positive, negative, and neutral emotional states. IBM SPSS was used for this analysis. The process included preliminary analysis of EEG data, creation of stimulus-based epochs (data division to cover specific time periods), calculation of mean values in frequency bands for each epoch, and comparison of mean values using statistical analyses. Paired data in frequency bands were analyzed together for each channel. To reduce the potential for Type I error in cases of multiple test repetitions, it was recommended to determine the significance level by dividing the statistical significance level ($p < .05$) by the number of comparisons (Huck, 2012). Therefore, the significance level for the analyses in question was set at .01 after dividing by five.

3. Results

R1. What is the impact of the pre-service teachers' emotions on instructional task performance concerning the components of EF skills?

The study investigates the impact of emotional states experienced by pre-service teachers during a simulation task on their teaching task performance. The simulation task was designed to include components of maintaining the rule (repetitive condition) and updating the rule when necessary (changing condition), which are fundamental to executive function (EF) skills. Short sequence data was collected and analyzed using lag analysis to determine the transition probabilities and z values for the correct or incorrect intervention method applied after experiencing certain emotions when encountering specific stimuli.

Table 1 displays the transition probability matrix, indicating the directions of transitions from rows to columns and the corresponding z values. The results shed light on how emotional states influence pre-service teachers' responses to different instructional stimuli, providing valuable insights into the interaction between emotions and EF skills during teaching tasks.

When examining Tables 1 and it is evident that the probability of applying the correct intervention method is significantly higher when individuals encounter a stimulus (changing condition) that requires them to find and apply a new intervention method while experiencing happiness ($p_{tr} = .4$, $z = 2.67$, $p < .05$). Conversely, the probability of applying the wrong intervention method when facing a stimulus (repetitive condition) in which pre-service teachers experience suprised in positive valence and need to continue applying the intervention method they found is significantly higher ($p_{tr} = .47$, $z = 2.21$, $p < .05$).

Furthermore, the probability of pre-service teachers who experience the negative valence emotion of contempt to apply the correct intervention method when they encounter a stimulus (repetitive condition) that requires them to continue applying the intervention method they found was found to be significantly higher ($p_{tr} = .67$, $z = 3.25$, $p < .05$). However, if the pre-service teachers experience anger when faced with a repetitive conditional stimulus, the probability of applying the wrong intervention method was statistically significant ($p_{tr} = .71$, $z = 2.04$, $p < .05$) (see Table 5).

Additionally, when sadness, fear, and disgust were experienced, the patterns regarding the probability of the correct or incorrect intervention method applied in any repetitive or changing conditional stimulus were not statistically significant ($p \geq .01$).

Table 1
z Residuals.

z Residuals	Incorrect intervention		Correct intervention	
	changing condition	*repetitive condition*	*changing condition*	*repetitive condition*
Happiness	−1.01	.53	2.67*	−2.10
Sadness	.99	−.54	−.96	.63
Anger	−.03	2.04*	−1.35	−.92
Contempt	−.91	−1.30	−1.36	3.25*
Disgust	.92	1.15	−.88	−1.14
Surprise	−.03	2.21*	−.43	−1.91
Fear	.27	−2.73	.93	1.83

Fig. 3 summarizes the statistically significant transitions.

RQ2. What is the influence of pre-service teachers' emotions on event-related oscillations, reflecting EF skill components such as working memory, cognitive flexibility, and inhibitory control, in a simulation-based teaching task?

Within the scope of this research question, we examined whether the brain oscillations reflecting EF skills of pre-service teachers differed according to the emotional states they experienced in the simulation. As stated in the method section, the emotional states of the pre-service teachers were analyzed with the valence dimension (positive-negative-neutral). In order to make inferences about EF skills, delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–25 Hz), and gamma (25–50 Hz) frequency bands were analyzed.

The results of the Wilcoxon Signed Ranks test conducted to examine whether the EF skill of the pre-service teachers differed according to whether they were neutral when experiencing a negative valence emotion are presented in Table 2. As seen in Table 2, a significant difference was found between the participants' oscillations in the alpha frequency band in negative-neutral emotional states for the F3 channel ($z = -3.16$, $p < .01$), F4 channel ($z = -3.33$, $p < .01$), F7 channel ($z = -3.13$, $p < .01$), F8 channel ($z = -3.13$, $p < .01$), and Fpz channel ($z = -3.36$, $p < .01$). When the rank means and sums of the difference scores are considered, it is seen that this difference is in favor of Positive Ranks, that is, negative mood states. On the other hand, no significant difference was found for Fp1 ($z = -2.48$, $p \geq .01$), Fp2 ($z = -2.38$, $p \geq .01$), and Fz channels ($z = -2.28$, $p \geq .01$) in the alpha frequency band in negative states.

The results of the Wilcoxon Signed Ranks test conducted to examine whether the EF skill of the pre-service teachers differed according to the neutral state while experiencing a positive valence emotion are presented in Table 3. As seen in Table 3, a significant difference was found between the participants' oscillations in the alpha frequency band for the F4 channel ($z = -2.95$, $p < .01$) and Fpz channel ($z = -2.51$, $p < .01$) in positive-neutral emotional states. When the rank mean and sums of the difference scores are taken into consideration, it is seen that this difference is in favor of Positive Ranks, that is, positive moods. On the other hand, no significant difference was found in the alpha frequency band for the F7 channel ($z = -2.35$, $p \geq .01$), F8 channel ($z = -1.57$, $p \geq .01$), Fp1 channel ($z = -1.07$, $p \geq .01$), Fp2 ($z = -3.29$, $p \geq .01$), and Fz channels ($z = -1.72$, $p \geq .01$).

In Table 4, the results of the Wilcoxon Signed Ranks test for the beta frequency were presented to examine whether the EF skill of the pre-service teachers differed according to whether they were neutral when experiencing a negative valence emotion. As can be seen in Tables 4 and in negative-neutral emotional states, the oscillations in the beta frequency band of the participants in the F3 channel ($z = -3.3$, $p < .01$), F4 channel ($z = -3.32$, $p < .01$), F7 channel ($z = -3.30$, $p < .01$), F8 channel ($z = -3.45$, $p < .01$), Fp1 ($z = -3.13$, $p < .01$), Fp2 ($z = -3.15$, $p < .01$), Fpz ($z = -3.31$, $p < .01$), and Fz channel ($z = -3.33$, $p < .01$). When the rank means and sums of the difference scores are considered, it is seen that this difference is in favor of Positive Ranks, that is, negative moods. On the other hand, Table 5 presents the results of the Wilcoxon Signed Ranks test regarding the oscillations in the beta frequency band of the participants in positive-neutral mood states. As seen in Table 5, no significant difference was found between the oscillations in the beta frequency band of the participants in positive-neutral emotional states in all channels ($p \geq .01$).

As shown in Table 6, a significant difference was observed in the gamma frequency band oscillations of participants between negative and neutral mood states for F3 channel ($z = -2.85$, $p < .01$) and F4 channel ($z = -3.02$, $p < .01$). Further examination of the rank mean and sums of the difference scores reveals that this difference favors Positive Ranks, representing negative moods. However, no significant difference was found in the gamma frequency band for F7 channel ($z = -2.36$, $p \geq$

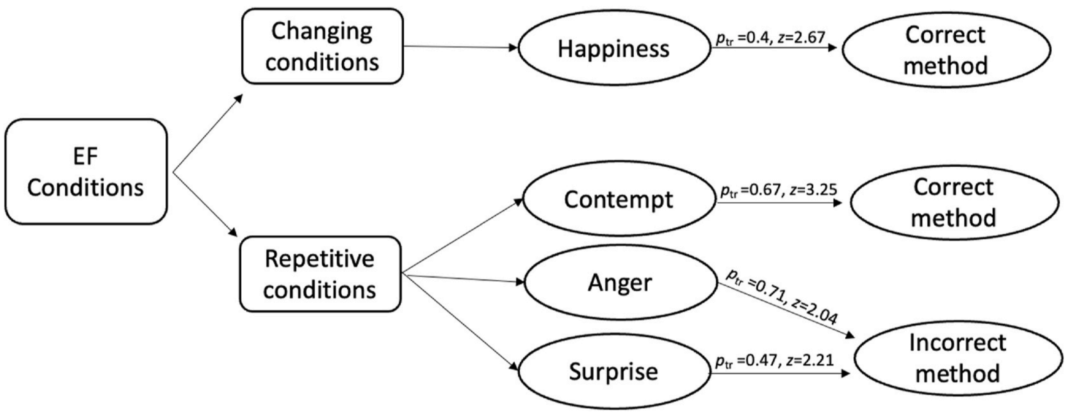

Fig. 3. Pre-service teachers' emotion-behavior patterns in the simulation task.

Table 2
Wilcoxon Signed ranks test results for alpha frequency oscillations in negative and neutral states.

Variables	*Ranks*	*n*	Mean Ranks	Sum of Ranks	*z*	*p*
Alpha2_F3 - Alpha1_F3	Negative Ranks	3	2.33	7.00	−3.16	.002*
	Positive Ranks	13	9.92	129.00		
	Equal	0				
Alpha2_F4- Alpha1_F4	Negative Ranks	1	1.50	1.5	−.3.33	.001*
	Positive Ranks	14	8.46	118.5		
	Equal	1				
Alpha2_F7- Alpha1_F7	Negative Ranks	3	2.50	7.5	−3135	.002*
	Positive Ranks	13	9.88	128.5		
	Equal	0				
Alpha2_F8- Alpha1_F8	Negative Ranks	2	3.75	7.5	−3.137	.002*
	Positive Ranks	14	9.18	128.5		
	Equal	0				
Alpha2_Fp1- Alpha1_Fp1	Negative Ranks	3	6.67	20.00	−2.487	.013
	Positive Ranks	13	8.92	116.00		
	Equal	0				
Alpha2_Fp2- Alpha1_Fp2	Negative Ranks	12	9.50	114.00	−2.383	.017
	Positive Ranks	4	5.50	22.00		
	Equal	0				
Alpha2_Fpz- Alpha1_Fpz	Negative Ranks	2	1.50	3.00	−3.368	.001*
	Positive Ranks	14	9.50	133.00		
	Equal	0				
Alpha2_Fz- Alpha1_Fz	Negative Ranks	2	12.00	24.00	−2.28	.023
	Positive Ranks	14	8.00	112.00		
	Equal	0				

Table 3
Wilcoxon Signed ranks test results for alpha frequency oscillations in positive and neutral states.

Variables	*Ranks*	*n*	Mean Ranks	Sum of Ranks	*z*	*p*
Alpha3_F3 - Alpha1_F3	Negative Ranks	3	3.17	9.50	−2.52	.012
	Positive Ranks	10	8.15	81.50		
	Equal	1				
Alpha3_F4- Alpha1_F4	Negative Ranks	0	.00	.00	−2.95	.003*
	Positive Ranks	11	6.00	66.00		
	Equal	3				
Alpha3_F7- Alpha1_F7	Negative Ranks	2	4.50	9.00	−2.35	.018
	Positive Ranks	10	6.90	69.00		
	Equal	2				
Alpha3_F8- Alpha1_F8	Negative Ranks	5	4.60	23.00	−1.57	.114
	Positive Ranks	8	8.50	68.00		
	Equal	1				
Alpha3_Fp1- Alpha1_Fp1	Negative Ranks	4	4.25	17.00	−1.07	.283
	Positive Ranks	6	6.33	38.00		
	Equal	4				
Alpha3_Fp2- Alpha1_Fp2	Negative Ranks	12	7.71	92.50	−3.29	.012
	Positive Ranks	2	6.25	12.50		
	Equal	0				
Alpha3_Fpz- Alpha1_Fpz	Negative Ranks	0	.00	.00	−2.51	.001*
	Positive Ranks	14	7.50	105.00		
	Equal	0				
Alpha3_Fz- Alpha1_Fz	Negative Ranks	5	5.10	25.50	−1.72	.085
	Positive Ranks	9	8.83	79.50		
	Equal	0				

.01), F8 channel ($z = -2.22, p \geq .01$), Fp1 ($z = -1.95, p \geq .01$), Fp2 ($z = -2.59, p \geq .01$), Fpz ($z = -2.04, p \geq .01$), and Fz channel ($z = -2.42$, $p \geq .01$).

Furthermore, Table 7 presents the results of the Wilcoxon Signed Ranks test for the oscillations in the gamma frequency band of participants in positive-neutral mood states. As demonstrated in Table 7, no significant difference was found between the gamma frequency band oscillations of participants in positive-neutral emotional states across all channels ($p \geq .01$).

4. Discussion and conclusion

4.1. Pre-service teachers' emotions and their instructional task performance

In the first research question, which examined the emotions and

Table 4
Wilcoxon Signed ranks test results for beta frequency oscillations in negative and neutral states.

Variables	Ranks	*n*	Mean Ranks	Sum of Ranks	*z*	*p*
Beta2_F3 - Beta1_F3	Negative Ranks	0	.00	.00	−3.30	.001*
	Positive Ranks	14	7.50	105.00		
	Equal	2				
Beta2_F4- Beta1_F4	Negative Ranks	0	.00	.00	−.3.32	.001*
	Positive Ranks	14	7.50	105.00		
	Equal	2				
Beta2_F7- Beta1_F7	Negative Ranks	1	2.00	2.00	−3,30	.001*
	Positive Ranks	14	8.43	118.00		
	Equal	1				
Beta2_F8- Beta1_F8	Negative Ranks	1	1.50	1.50	−3.45	.001*
	Positive Ranks	15	8.97	134.5		
	Equal	0				
Beta2_Fp1- Beta1_Fp1	Negative Ranks	3	2.50	7.50	−3.13	.002*
	Positive Ranks	13	9.88	128.50		
	Equal	0				
Beta2_Fp2- Beta1_Fp2	Negative Ranks	2	2.25	4.50	−3.15	.002*
	Positive Ranks	13	8.88	115.50		
	Equal	1				
Beta2_Fpz- Beta1_Fpz	Negative Ranks	2	2.00	4.00	−3.31	.001*
	Positive Ranks	14	9.43	132.00		
	Equal	0				
Beta2_Fz- Beta1_Fz	Negative Ranks	1	1.50	1.50	−3.33	.001*
	Positive Ranks	14	8.46	118.50		
	Equal	1				

Table 5
Wilcoxon Signed ranks test results for beta frequency oscillations in positive and neutral states.

	Ranks	*n*	Mean Ranks	Sum of Ranks	*z*	*p*
Beta3_F3 - Beta1_F3	Negative Ranks	4	3.75	15.00	−2.145	.032
	Positive Ranks	9	8.44	76.00		
	Equal	1				
Beta3_F4- Beta1_F4	Negative Ranks	3	2.33	7.00	−2.317	.020
	Positive Ranks	8	7.38	59.00		
	Equal	3				
Beta3_F7- Beta1_F7	Negative Ranks	3	2.00	6.00	−2.199	.028
	Positive Ranks	7	7.00	49.00		
	Equal	4				
Beta3_F8- Beta1_F8	Negative Ranks	1	3.50	3.50	−2.628	.012
	Positive Ranks	10	6.25	62.50		
	Equal	3				
Beta3_Fp1- Beta1_Fp1	Negative Ranks	4	5.38	21.50	−1.681	.093
	Positive Ranks	9	7.72	69.50		
	Equal	1				
Beta3_Fp2- Beta1_Fp2	Negative Ranks	6	4.58	27.50	−1.264	.206
	Positive Ranks	7	9.07	63.50		
	Equal	1				
Beta3_Fpz- Beta1_Fpz	Negative Ranks	4	3.00	12.00	−2.135	.033
	Positive Ranks	8	8.25	66.00		
	Equal	2				
Beta3_Fz- Beta1_Fz	Negative Ranks	3	3.00	9.00	−2.361	.018
	Positive Ranks	9	7.67	69.00		
	Equal	2				

teaching task performance of pre-service teachers based on the type of stimuli encountered in the simulation, it was observed that when individuals encountered a stimulus (changing condition) in which they had to find and apply a new intervention method while experiencing happiness, they were significantly more likely to apply the correct intervention method. Conversely, pre-service teachers who experienced surprise in a positive valence, when faced with a stimulus (repetitive condition) that required them to continue applying the intervention method they found, had a higher probability of applying the wrong intervention method.

The literature explains this finding by the cognitive factors associated with cognitive flexibility and working memory, components of the EF skill involved in emotions of positive valence. Happiness, being an actively experienced emotion with a high level of arousal (Russell & Mehrabian, 1977), is known to induce dopamine release, thereby increasing cognitive control and enhancing individuals' performance in tasks that require EF skills (Isen, 1999; Ashby et al., 1999). As it is known that pre-service teachers who experience joy during their teaching practice have increased self-efficacy (Bach & Hagenauer, 2022), it is assumed that this situation also increases the performance of pre-service teachers. Indeed, when pre-service teachers perceive classroom disruptions to be at a level where they can control them, they use positive emotion regulation strategies (Kumschick et al., 2023). However, positive moods may cause individuals to reduce their attention to stimuli, leading to more superficial, less active, less systematic, and less detailed information processing compared to negative moods (Forgas, 2013). In this study, no significant pattern was found regarding the correct performance of individuals experiencing happiness in repetitive conditions. On the other hand, pre-service teachers who experienced surprised tended to apply the wrong intervention method when encountering repetitive condition stimuli that required them to maintain the intervention method they found. This result indicates that some emotions, such as surprise, which exhibit high arousal levels and may be considered positive/neutral, are not always supportive of task performance related with EF skills.

Rather than assuming that positive emotions will solely increase cognitive control and positively affect EF skills, research has also explored how they contribute to the components of EF skills. For instance, Davis (2009) found that positive emotions enhance individuals' cognitive flexibility and contribute to creativity by directing attention to the required stimulus. Mitchell and Phillips (2007) found that positive emotions support creativity and cognitive flexibility but negatively affect working memory performance and inhibitory control. Accordingly, the happiness experienced in the simulation task appears to support better performance in changing conditions.

On the other hand, pre-service teachers who experienced negative valence, specifically contempt, were significantly more likely to apply the correct intervention method when faced with a stimulus (repetitive condition) that required them to continue applying the intervention method they found. The nature of contempt involves a short-lived and fading emotional experience (Brans & Verduyn, 2014). According to the mood-as-information theory, individuals realize the negative situation

Table 6
Wilcoxon Signed ranks test results for gamma frequency oscillations in negative and neutral states.

Variables	Ranks	*n*	Mean Ranks	Sum of Ranks	*z*	*p*
Gamma2_F3 - Gamma1_F3	Negative Ranks	4	3.25	13.00	−2.85	.004*
	Positive Ranks	12	10.25	123.00		
	Equal	0				
Gamma2_F4-Gamma1_F4	Negative Ranks	3	3.33	10.00	−.3.02	.003*
	Positive Ranks	13	9.69	126.00		
	Equal	0				
Gamma2_F7-Gamma1_F7	Negative Ranks	2	11.25	22.50	−2.36	.018
	Positive Ranks	14	8.11	113.50		
	Equal	0				
Gamma2_F8-Gamma1_F8	Negative Ranks	3	8.33	25.00	−2.22	.02
	Positive Ranks	13	8.54	111.00		
	Equal	0[l]				
Gamma2_Fp1-Gamma1_Fp1	Negative Ranks	3	10.17	30.50	−1.95	.051
	Positive Ranks	13	8.12	105.50		
	Equal	0				
Gamma2_Fp2-Gamma1_Fp2	Negative Ranks	2	9.00	18.00	−2.59	.01
	Positive Ranks	14	8.43	118.00		
	Equal	0				
Gamma2_Fpz-Gamma1_Fpz	Negative Ranks	3	9.50	28.50	−2.04	.04
	Positive Ranks	13	8.27	107.50		
	Equal	0				
Gamma2_Fz-Gamma1_Fz	Negative Ranks	3	5.83	17.50	−2.42	.015
	Positive Ranks	12	8.54	102.50		
	Equal	1				

Table 7
Wilcoxon Signed ranks test results for gamma frequency oscillations in positive and neutral states.

	Ranks	*n*	Mean Ranks	Sum of Ranks	*z*	*p*
Gamma3_F3 - Gamma1_F3	Negative Ranks	4	3.38	13.50	−2.242	.025
	Positive Ranks	9	8.61	77.50		
	Equal	1				
Gamma3_F4-Gamma1_F4	Negative Ranks	2	5.75	11.50	−1.917	.055
	Positive Ranks	9	6.06	54.50		
	Equal	3				
Gamma3_F7-Gamma1_F7	Negative Ranks	7	5.07	35.50	−.702	.483
	Positive Ranks	6	9.25	55.50		
	Equal	1				
Gamma3_F8-Gamma1_F8	Negative Ranks	3	5.67	17.00	−2.005	.045
	Positive Ranks	10	7.40	74.00		
	Equal	1				
Gamma3_Fp1-Gamma1_Fp1	Negative Ranks	5	4.80	24.00	−1.181	.238
	Positive Ranks	7	7.71	54.00		
	Equal	2				
Gamma3_Fp2-Gamma1_Fp2	Negative Ranks	4	3.75	15.00	−1.605	.108
	Positive Ranks	7	7.29	51.00		
	Equal	3				
Gamma3_Fpz-Gamma1_Fpz	Negative Ranks	5	6.40	32.00	−.95	.342
	Positive Ranks	8	7.38	59.00		
	Equal	1				
Gamma3_Fz-Gamma1_Fz	Negative Ranks	3	5.00	15.00	−1.603	.109
	Positive Ranks	8	6.38	51.00		
	Equal	3				

during negative emotions and process the stimulus with heightened attention and analytical processing style (Forgas, 2017). As a result, pre-service teachers may have exhibited successful performance in maintaining the rule while experiencing this negative valence emotion, characterized by a low activation level.

On the contrary, when pre-service teachers experienced anger upon encountering repetitive conditional stimuli, they were more likely to apply the wrong intervention method. While the results obtained for the feeling of contempt align with the general principles of affect theory and knowledge, the findings related to anger in the study contradict these principles. Anger, as an actively experienced emotion with negative valence and high arousal level (Russell & Mehrabian, 1977), has been studied differently in the context of EF skills. Shields et al. (2016) found that anger did not have an impairing effect on EF skills in the Wisconsin card matching test, whereas anxiety had an impairing effect. In a neuroimaging study conducted by Yeung et al. (2021) using FNIRS with healthy young individuals during the n-back task, it was found that high-intensity stress and depression caused decreased activation in the prefrontal cortex (PFC), indicating an impairing effect on working memory. Gabel and McAuley (2018) considered individual differences in their study and found that individuals with high emotional reactivity exhibited higher performance in the EF task when experiencing negative emotions, while individuals with low emotional reactivity showed lower performance under the same conditions. Although the results obtained for anger may seem to contradict the affect theory as information, it is important to consider current neuroimaging studies and individual differences, as anger is an intense emotion by nature. In the simulation task used in this study, students' disruptive behaviour, which is one of the strongest predictors of teachers' negative emotions (Junker et al., 2021), was repeatedly presented to pre-service teachers, so anger may have been felt intensely. Classroom management is already known to be a very challenging situation (Wolff et al., 2021). In teacher education studies, anger has been found to cause pre-service teachers to have low self-efficacy, and it has been emphasised that this situation causes a decrease in student engagement (Bach & Hagenauer, 2022). Furthermore, pre-service teachers' negative emotions lead to a decrease in confidence, poor decision making, burnout and frustration (McCarthy et al., 2015).

4.2. Pre-service teachers' emotions and their executive function skills

When evaluating the executive function (EF) skills of pre-service teachers according to their emotional states, it was observed that the alpha frequency was higher in negative valence emotional states compared to neutral states. Conversely, when pre-service teachers experienced positive emotions, a higher level of alpha frequency was found in the alpha frequency band in the F4 and Fpz channels compared to neutral states. This difference observed in the alpha band aligns with the working memory, cognitive flexibility, and inhibitory control components of EF skills in studies reported in the literature. Scharinger et al. (2015) observed a significant increase in the alpha band in tasks requiring a high level of updating in working memory. Since high levels of updating also necessitate high levels of inhibition, the increase in alpha band was associated with inhibition behavior. Studies dealing with working memory performance found increased alpha oscillation in the prefrontal cortex of the participants during the task (Sauseng et al., 2005).

Additionally, higher levels of beta band oscillation were observed in all channels, and higher gamma oscillation was observed in F3 and F4 channels when pre-service teachers experienced negative valence emotional states during the teaching task compared to neutral states. However, no significant difference was observed in beta and gamma band oscillations when pre-service teachers experienced positive emotional states compared to neutral states. Increased beta activity is typically observed in situations that require inhibitory control (Huster et al., 2013), particularly when it is necessary to maintain and repeatedly apply associated rules (Onton et al., 2005). Malik and Amin (2017) found that beta oscillation increased when solving problems that demanded intense attention. Similar to beta oscillation, gamma oscillation is closely related to working memory and attention (Jensen et al., 2007).

These findings suggest that the emotional states of pre-service teachers can influence their executive function skills, as reflected in the patterns of alpha, beta, and gamma oscillations. It is known that teachers' high levels of EF skills are associated with high levels of self-regulation, adaptability, good lesson planning and success in classroom management (Manowaluilou, 2021). It is also emphasised that teachers with high EF skills are successful in regulating attention and emotional responses and in problem solving (Hiver et al., 2021). Considering the interplay of emotions and cognitive processes, these results provide valuable insights into understanding the mechanisms underlying EF skills and their modulation by emotions. These findings are limited to results obtained from complex classroom scenarios requiring EF skills of pre-service teachers in a computer simulation environment. Although the relationship between EF skills and emotions has been demonstrated in previous studies, it is promising to obtain similar results in a teacher education simulation that models an authentic classroom. Indeed, it is known that pre-service teachers' negative emotions decrease over time in a VR environment where systematic observations and classroom environments are modelled (Stavroulia et al., 2019). These results suggest that simulation can be used as a complementary element in teacher education, in addition to teaching practice, as it requires the use of EF skills and triggers emotions similar to those in the real classroom.

4.3. Conclusion

While some emotions contribute to affective states in the classroom, others have positive effects on cognitive performance. The literature frequently emphasizes that happiness contributes to affective variables such as creating a positive classroom climate and establishing good relationships between teachers and students. According to the results of this study, happiness positively affects cognitive flexibility and contributes to better performance in changing conditions. Based on these findings, it can be inferred that individuals experiencing positive emotions in the teaching context can better focus on new situations and perform more effectively. Considering the dynamic nature of classrooms, students, and the teaching environment, it is essential for teachers to experience positive emotions, as it enables them to readapt to changing conditions and perform well in the classroom.

Regarding the other results obtained in this research, it can be stated that less active negative emotions (such as contempt) positively affect the performance in maintaining a rule. Conversely, actively experienced high arousal emotions such as anger and surprise negatively affected the ability to maintain a found rule. From this perspective, non-intense negative emotions experienced in the teaching context contribute to task performance, specifically reflecting working memory performance. Therefore, such negative emotions should not be considered completely undesirable, and their regulation in the classroom is not crucial. However, due to the disruptive effect of highly intense-arousal emotions, various intervention methods may be necessary when pre-service teachers experience such emotions. Simulations providing frequent repetition and detailed suggestions, as used in this study, along with intelligent teaching systems and mentor support, can be employed. These mediators can help pre-service teachers discover the effects of intense and actively experienced negative emotions during teaching and engage in a re-appraisal process for these emotions in the teaching context. Designing a system that provides suggestions based on these and similar findings will benefit pre-service teachers in creating a balance of positive and negative emotions, ultimately enhancing their teaching performance.

Additionally, the patterns regarding the probability of being correct or incorrect in the intervention method applied during repetitive or changing conditional stimuli when experiencing sadness, fear, and disgust were not statistically significant in this study. As the study used natural stimuli similar to the natural environment, individuals experienced these emotions in a limited number of stimuli presented in the simulation, which may explain the absence of significant patterns. Future studies could employ mood induction methods to explore the interaction between specific emotions and EF skills more comprehensively.

The findings of the second research question of the study further support the results obtained from the first research question. The increased alpha, beta, and gamma oscillations in pre-service teachers experiencing negative emotions explain their ability to apply the correct intervention method in repetitive conditions while experiencing negative emotions. Consistent with findings from other studies in the literature, alpha, beta, and gamma activity increase in working memory tasks when it is necessary to repeatedly apply the appropriate rule and in situations requiring intense attention. Given that mild negative emotions are known to improve focus and attention, the heightened focus of attention in negative situations contributes to the successful maintenance of the rule in working memory, which is reflected in the performance of pre-service teachers and the increase in relevant frequency bands. Furthermore, studies in the literature have linked high alpha oscillation to good working memory performance, working memory updating, and sometimes inhibitory control. The fact that alpha oscillation is high in positive emotions provides evidence that pre-service teachers can perform well by applying the correct intervention method in changing conditions when experiencing positive valence emotional states. In such cases, pre-service teachers must prevent the continuation of the rule they have applied before and update their working memory by finding a new and correct rule.

5. Limitations and implications

The findings of this study are limited to teacher candidates in a task in a simulation environment. Although planning a lesson in a simulation, responding appropriately to virtual student misbehaviour, and taking the necessary steps to teach by demonstrating blocking behaviour when necessary require EF skills, it is not possible to model all situations observed in a real classroom environment where teachers make instructional decisions. Therefore, in the simulated task, the pre-service teachers did not teach a lesson or make instructional decisions as they would in a real classroom. For this reason, teacher emotions during teaching and instructional decision making could not be investigated in this study. In addition, the sample selection criteria for this study are that the participants have taken a classroom management course and have no previous teaching experience. Although these criteria are met, two of the respondents in the study are graduates. In this context, it is possible that they performed differently from current pre-service teachers in the simulation task. This situation can be considered a limitation of the study. In future studies, the study can be repeated with teachers in a real classroom environment.

In light of the limitations of this study, it is recommended that future studies examine teachers' emotions and the interaction of emotions with other cognitive variables in situations that require instructional decision-making, such as when students do not understand the lesson or want to ask questions about the lesson. Based on the current study's results, it is suggested that future research should compare oscillations related to high and low arousal levels, negative and positive emotional states to gain more detailed information. Additionally, in the context of teacher education, there is a need for supportive systems that help teachers become aware of their positive and negative emotions and provide suggestions on how to maintain a balanced emotional state during teaching, rather than merely focusing on feeling good. Integrating support systems into micro-teaching processes can enable more focused feedback to be given to pre-service teachers as they work towards achieving teaching objectives, thereby supporting their social-emotional development. In this context, to create a pool of suggestions for supporting pre-service teachers, further research is required on cognitive individual differences, various emotional states, and their effects on the student-teacher relationship. Integrating the findings from such research into the pool of suggestions and incorporating them into the teacher education process will positively contribute to the overall teacher training process.

CRediT authorship contribution statement

Şeyma Çağlar-Özhan: Writing – original draft, Methodology, Investigation, Conceptualization. **Arif Altun:** Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors state that there are no conflicts of interest associated with this paper. We confirm that this manuscript is not under review elsewhere, involves no conflict of interest, involves data that were collected ethically and involves no prior or duplicate publication. We confirm that the manuscript has been read and approved by all authors.

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Data availability

Data will be made available on request.

References

Abhang, P. A., Gawali, B. W., & Mehrotra, S. C. (2016). Introduction to EEG-and speech-based emotion recognition. *Elsevier*. https://doi.org/10.1016/B978-0-12-804490-2.00003-8

Ashby, F. G., Isen, A. M., & Turken, U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106*, 529–550. https://doi.org/10.1037/0033-295X.106.3.529

Audrin, C., & Hascoët, M. (2024). Ode to joy: The impact of enjoyment on pre-service teacher persistence. *Teaching and Teacher Education, 137*, Article 104406. https://doi.org/10.1016/j.tate.2024.104406

Bach, A., & Hagenauer, G. (2022). Joy, anger, and anxiety during the teaching practicum: How are these emotions related to dimensions of pre-service teachers' self-efficacy? *Zeitschrift für Bildungsforschung, 12*(2), 295–311. https://doi.org/10.1007/s35834-022-00314-z

Baddeley, A. (1992). Working memory. *Science, 255*(5044), 556–559. https://doi.org/10.1126/science.1736359

Bakeman, R., & Gottman, J. M. (1997). *Observing interaction: An introduction to sequential analysis*. Cambridge University Press. https://doi.org/10.1017/CBO9780511527685

Başar, E. (1999). *Brain function and oscillations*. Springer. https://doi.org/10.1007/978-3-642-72192-2, 2nd ed.

Başar, E. (2012). A review of alpha activity in integrative brain function: Fundamental physiology, sensory coding, cognition and pathology. *International Journal of Psychophysiology, 86*(1), 1–24. https://doi.org/10.1016/j.ijpsycho.2012.07.002

Bayazıt, T. (2018). Event related potentials (ERP). *Journal of Medical Clinics, 1*(1), 59–65. https://dergipark.org.tr/tr/pub/atk/issue/38771/451155.

Blikstein, P., Gomes, J. S., Akiba, H. T., & Schneider, B. (2017). The effect of highly scaffolded versus general instruction on students' exploratory behavior and arousal. *Technology, Knowledge and Learning, 22*(1), 105–128. https://doi.org/10.1007/s10758-016-9291-y

Brans, K., & Verduyn, P. (2014). Intensity and duration of negative emotions: Comparing the role of appraisals and regulation strategies. *PLoS One, 9*(3), Article e92410. https://doi.org/10.1371/journal.pone.0092410

Brosch, T., Scherer, K., Grandjean, D., & Sander, D. (2013). The impact of emotion on perception, attention, memory, and decision-making. *Swiss Medical Weekly, 143*. https://doi.org/10.4414/smw.2013.13786. w13786-w13786.

Burić, I., & Frenzel, A. C. (2023). Teacher emotions are linked with teaching quality: Cross-sectional and longitudinal evidence from two field studies. *Learning and Instruction, 88*, Article 101822. https://doi.org/10.1016/j.learninstruc.2023.101822

Çağlar-Özhan, Ş., & Altun, A. (2019). *Eğitim teknolojisi Araştırmalarında Duygular: Bir İçerik Analizi* [Konferans Sunum Özeti]. *Uluslararası Öğretim Teknolojileri ve Öğretmen Eğitimi Sempozyumu Programı (ITTES), Antalya, Türkiye, 7*. https://2019.ittes.org.tr/dosyalar/files/ozetler.pdf.

Canas, J., Quesada, J., Antolí, A., & Fajardo, I. (2003). Cognitive flexibility and adaptability to environmental changes in dynamic complex problem-solving tasks. *Ergonomics, 46*(5), 482–501. https://doi.org/10.1080/0014013031000061640

Clark, M. S., & Isen, A. M. (1982). Toward understanding the relationship between feeling states and social behavior. *Cognitive social psychology, 73*, 108. https://psycnet.apa.org/record/2011-28557-005.

Corcoran, R. P., & O'Flaherty, J. (2017). Executive function during teacher preparation. *Teaching and Teacher Education, 63*, 168–175. https://doi.org/10.1016/j.tate.2016.12.023

Davis, M. A. (2009). Understanding the relationship between mood and creativity: A meta-analysis. *Organizational Behavior and Human Decision Processes, 100*(1), 25–38. https://doi.org/10.1016/j.learninstruc.2017.04.001

Dmochowski, J. P., Sajda, P., Dias, J., & Parra, L. C. (2012). Correlated components of ongoing EEG point to emotionally laden attention–a possible marker of engagement? *Frontiers in human neuroscience, 6*, 112, 10.3389%2Ffnhum.2012.00112.

Ekman, P. (1970). Universal facial expressions of emotions. *California mental health research digest, 8*(4), 151–158. https://psycnet.apa.org/record/1972-06605-001.

Ekman, P. (1993). Facial expression and emotion. *American Psychologist, 48*(4), 384–392. https://doi.org/10.1037/0003-066X.48.4.384

Ekman, P. (2007). The directed facial action task. In J. A. Coan, & J. J. B. Allen (Eds.), *Handbook of emotion elicitation and assessment* (pp. 47–53). Oxford University Press.

Ekman, P., & Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of personality and social psychology, 17*(2), 124. https://doi.org/10.1037/h0030377

Forgas, J. P. (2013). Don't worry, be sad! On the cognitive, motivational, and interpersonal benefits of negative mood. *Current Directions in Psychological Science, 22*(3), 225–232. https://doi.org/10.1177/0963721412474458

Forgas, J. P. (2017). Mood effects on cognition: Affective influences on the content and process of information processing and behavior. In M. Jeon (Ed.), *Emotions and affect in human factors and human-computer interaction* (pp. 89–122). Elseiver Academic Press.

Forgas, J. P., & East, R. (2008). On being happy and gullible: Mood effects on skepticism and the detection of deception. *Journal of Experimental Social Psychology, 44*(5), 1362–1367. https://doi.org/10.1016/j.jesp.2008.04.010

Frenzel, A. C., Dindar, M., Pekrun, R., Reck, C., & Marx, A. K. (2024). Joy is reciprocally transmitted between teachers and students: Evidence on facial mimicry in the classroom. *Learning and Instruction, 91*, Article 101896. https://doi.org/10.1016/j.learninstruc.2024.101896

Gabel, M. S., & McAuley, T. (2018). Does mood help or hinder executive functions? Reactivity may be the key. *Personality and Individual Differences, 128*, 94–99. https://doi.org/10.1016/j.paid.2018.02.027

Gijselaers, H. J., Meijs, C., Neroni, J., Kirschner, P. A., & de Groot, R. H. (2017). Updating and not shifting predicts learning performance in young and middle-aged adults. *Mind, Brain, and Education, 11*(4), 190–200. https://doi.org/10.1111/mbe.12147

Gómez-Chacón, I. M., & Marbán, J. M. (2024). Epistemic emotions and pre-service mathematics teachers' knowledge for teaching. *ZDM–Mathematics Education*, 1–15.

Graesser, A. C. (2020). Emotions are the experiential glue of learning environments in the 21st century. *Learning and Instruction, 70*, Article 101212.

Hargreaves, A. (1998). The emotional practice of teaching. *Teaching and Teacher Education, 14*(8), 835–854. https://doi.org/10.1016/S0742-051X(98)00025-0

Hascher, T., & Waber, J. (2021). Teacher well-being: A systematic review of the research literature from the year 2000–2019. *Educational Research Review, 34*, Article 100411.

Hoferichter, F., & Jentsch, A. (2024). The effects of an online positive psychology intervention on pre-service teachers' efficacy, ability to cope and emotional regulation. *British Educational Research Journal*. https://doi.org/10.1002/berj.3855

Huck, S. W. (2012). *Reading statistics and research*. Pearson.

Huster, R. J., Enriquez-Geppert, S., Lavallee, C. F., Falkenstein, M., & Herrmann, C. S. (2013). Electroencephalography of response inhibition tasks: Functional networks

and cognitive contributions. *International Journal of Psychophysiology, 87*(3), 217–233. https://doi.org/10.1016/j.ijpsycho.2012.08.001
Irak, M., Soylu, C., & Çapan, D. (2014). The relationships between the Wisconsin Card Sorting Test and event-related brain potentials. *Turkish Journal of Psychology, 29*(74). https://www.psikolog.org.tr/tr/yayinlar/dergiler/1031828/tpd1300443320140000m000050.pdf.
Isen, A. M. (1999). Positive affect. In T. Dalgleish, & M. Powers (Eds.), *Facial expression analysis: The complete pocket guideThe handbook of cognition and emotion. Hillsdale Press. iMotions*. iMotions A/S, 2021 https://imotions.com/guides/on.
Jensen, O., Kaiser, J., & Lachaux, J. P. (2007). Human gamma-frequency oscillations associated with attention and memory. *Trends in neurosciences, 30*(7), 317–324. https://doi.org/10.1080/00221309.1936.9713141
Ji, Y., Oubibi, M., Chen, S., Yin, Y., & Zhou, Y. (2022). Pre-service teachers' emotional experience: Characteristics, dynamics, and sources amid the teaching practicum. *Frontiers in Psychology, 13*, Article 968513. https://doi.org/10.3389/fpsyg.2022.968513
Junker, R., Donker, M. H., & Mainhard, T. (2021). Potential classroom stressors of teachers: An audiovisual and physiological approach. *Learning and Instruction, 75*, Article 101495. https://doi.org/10.1016/j.learninstruc.2021.101495
Kamkar, N. H., & Morton, J. B. (2017). CanDiD: A framework for linking executive function and education. *Frontiers in Psychology, 8*, 1187. https://doi.org/10.3389/fpsyg.2017.01187
Karakaş, S., Erzengin, Ö. U., & Başar, E. (2000). The genesis of human event-related responses explained through the theory of oscillatory neural assemblies. *Neuroscience Letters, 285*(1), 45–48. https://doi.org/10.1016/s0304-3940(00)01022-3
Kleinginna, P. R., & Kleinginna, A. M. (1981). A categorized list of emotion definitions, with suggestions for a consensual definition. *Motivation and Emotion, 5*(4), 345–379. https://doi.org/10.1007/BF00992553
Korosec, K. (2021). Emotion detection software startup Affectiva acquired for $73.5M. MIT Media Lab. https://www.media.mit.edu/articles/emotion-detection-software-startup-affectiva-acquired-for-73-5m/.
Kulke, L., Feyerabend, D., & Schacht, A. (2020). A comparison of the Affectiva iMotions Facial Expression Analysis Software with EMG for identifying facial expressions of emotion. *Frontiers in Psychology, 11*, 329. https://doi.org/10.3389/fpsyg.2020.00329
Kumschick, I. R., Torchetti, L., Gasser, L., & Tettenborn, A. (2023). How controllable versus uncontrollable cognitions affect emotion processing during classroom disruptions: A video study with preservice teachers. *Teaching and Teacher Education, 135*, Article 104317. https://doi.org/10.1016/j.tate.2023.104317
Lankinen, K., Saari, J., Hari, R., & Koskinen, M. (2014). Intersubject consistency of cortical MEG signals during movie viewing. *NeuroImage, 92*, 217–224. https://doi.org/10.1016/j.neuroimage.2014.02.004
Li, P. H., Mayer, D., & Malmberg, L. E. (2024). Student engagement and teacher emotions in student-teacher dyads: The role of teacher involvement. *Learning and Instruction, 91*, Article 101876. https://doi.org/10.1016/j.learninstruc.2024.101876
Malik, A. S., & Amin, H. U. (2017). *Designing EEG experiments for studying the brain: Design code and example datasets*. Academic Press.
Manowaluilou, N. (2021). Development of executive functions and support systems for student teachers in Thailand. *Higher Education Studies, 11*(4), 116–127.
McCrae, R. R., & John, O. P. (1992). An introduction to the five-factor model and its applications. *Journal of Personality, 60*(2), 175–215. https://doi.org/10.1111/j.1467-6494.1992.tb00970.x
MIT Media Lab. (2021). *Affectiva in-cabin AI*. MIT Media Lab. https://www.media.mit.edu/events/affectiva-in-cabin-ai/.
Mitchell, R. L., & Phillips, L. H. (2007). The psychological, neurochemical and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. *Neuropsychologia, 45*(4), 617–629. https://doi.org/10.1016/j.neuropsychologia.2006.06.030
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734
Onton, J., Delorme, A., & Makeig, S. (2005). Frontal midline EEG dynamics during working memory. *NeuroImage, 27*(2), 341–356. https://doi.org/10.1016/j.neuroimage.2005.04.014
Park, S., & Ryu, J. (2019). Exploring preservice teachers' emotional experiences in an immersive virtual teaching simulation through facial expression recognition. *International Journal of Human-Computer Interaction, 35*(6), 521–533. https://doi.org/10.1080/10447318.2018.1469710
Patrawala, N. M. (2018). *Teachers' executive functioning abilities and levels of occupational stress (Unpublished doctoral dissertation)*. University of Northern Colorado.
Pekrun, R., & Linnenbrink-Garcia, L. (2014). Introduction to emotions in education. In R. Pekrun, & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 1–10). Routledge.
Picazio, S., Veniero, D., Ponzo, V., Caltagirone, C., Gross, J., Thut, G., & Koch, G. (2014). Prefrontal control over motor cortex cycles at beta frequency during movement inhibition. *Current Biology, 24*(24), 2940–2945. https://doi.org/10.1016/j.cub.2014.10.043
Plancher, G., Massol, S., Dorel, T., & Chainay, H. (2019). Effect of negative emotional content on attentional maintenance in working memory. *Cognition & Emotion, 33*(7), 1489–1496. https://doi.org/10.1080/02699931.2018.1561420
Ritter, S. M., Damian, R. I., Simonton, D. K., van Baaren, R. B., Strick, M., Derks, J., & Dijksterhuis, A. (2012). Diversifying experiences enhance cognitive flexibility. *Journal of Experimental Social Psychology, 48*(4), 961–964. https://doi.org/10.1016/j.jesp.2012.02.009
Rodriguez, V. (2013). The human nervous system: A framework for teaching and the teaching brain. *Mind, Brain, and Education, 7*(1), 2–12. https://doi.org/10.1111/mbe.12000
Russell, J. A., & Mehrabian, A. (1977). Evidence for a three-factor theory of emotions. *Journal of Research in Personality, 11*(3), 273–294. https://doi.org/10.1016/0092-6566(77)90037-X
Sargent, K., Chavez-Baldini, U., Master, S. L., Verweij, K. J., Lok, A., Sutterland, A. L., & Nieman, D. H. (2021). Resting-state brain oscillations predict cognitive function in psychiatric disorders: A transdiagnostic machine learning approach. *NeuroImage: Clinical, 30*, Article 102617. https://doi.org/10.1016/j.nicl.2021.102617
Sauseng, P., Klimesch, W., Schabus, M., & Doppelmayr, M. (2005). Fronto-parietal EEG coherence in theta and upper alpha reflect central executive functions of working memory. *International Journal of Psychophysiology, 57*(2), 97–103. https://doi.org/10.1016/j.ijpsycho.2005.03.018
Scharinger, C., Soutschek, A., Schubert, T., & Gerjets, P. (2015). When flanker meets the n-back: What EEG and pupil dilation data reveal about the interplay between the two central-executive working memory functions inhibition and updating. *Psychophysiology, 52*(10), 1293–1304. https://doi.org/10.1111/psyp.12500
Shields, G. S., Moons, W. G., Tewell, C. A., & Yonelinas, A. P. (2016). The effect of negative affect on cognition: Anxiety, not anger, impairs executive function. *Emotion, 16*(6), 792, 10.1037%2Femo0000151.
Shu, L., Xie, J., Yang, M., Li, Z., Li, Z., Liao, D., Xu, X., & Yang, X. (2018). A review of emotion recognition using physiological signals. *Sensors, 18*(7), 2074. https://doi.org/10.3390/s18072074
Stavroulia, K. E., Christofi, M., Baka, E., Michael-Grigoriou, D., Magnenat-Thalmann, N., & Lanitis, A. (2019). Assessing the emotional impact of virtual reality-based teacher training. *The International Journal of Information and Learning Technology, 36*(3), 1–10. https://doi.org/10.1108/IJILT-11-2018-0127
Swartz Center for Computational Neuroscience [SCCN]. (2024). EEGLAB tutorials. https://eeglab.org/tutorials/.
Taylor, L. P., Newberry, M., & Clark, S. K. (2020). Patterns and progression of emotion experiences and regulation in the classroom. *Teaching and Teacher Education, 93*, Article 103081. https://doi.org/10.1016/j.tate.2020.103081
Wang, Y., Song, W., Tao, W., Liotta, A., Yang, D., Li, X., & Zhang, W. (2022). A systematic review on affective computing: Emotion models, databases, and recent advances. *Information Fusion, 83*, 19–52. https://doi.org/10.1016/j.inffus.2022.03.009
Wolff, C. E., Jarodzka, H., & Boshuizen, H. P. (2021). *Classroom management scripts: A theoretical model contrasting expert and novice teachers' knowledge and awareness of classroom events. Educational Psychology Review, 33*(1), 131–148. https://doi.org/10.1007/s10648-020-09542-0
Woods, P., & Jeffrey, B. (1996). *Teachable moments: The art of creative teaching in primary schools*. Open University Press.
Yang, H. (2019). The nexus between pre-service teachers' emotional experience and cognition during professional experience. *Australian Educational Researcher, 46*(5), 799–825. https://doi.org/10.1007/s13384-019-00320-8
Yeung, M. K., Lee, T. L., & Chan, A. S. (2021). Negative mood is associated with decreased prefrontal cortex functioning during working memory in young adults. *Psychophysiology, 58*(6), Article e13802. https://doi.org/10.1111/psyp.13802
Yordanova, J., & Kolev, V. (1998). Event-related alpha oscillations are functionally associated with P300 during information processing. *NeuroReport, 9*(14), 3159–3164. https://doi.org/10.1097/00001756-199810050-00007
Zelazo, P. D., Blair, C. B., & Willoughby, M. T. (2017). *Executive function: Implications for education (NCER 2017-2000)*. National Center for Education Research. https://files.eric.ed.gov/fulltext/ED570880.pdf.