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RESEARCH ARTICLE

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Identifying the Most Suitable Learning Techniques Based on Cognitive and Physiological Behavior

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Abstract

Numerous learning platforms and teaching methods have emerged in recent years. Identifying effective approaches is crucial for enhancing the productivity of education. This study aimed to determine the most effective learning tactics for small face-to-face management classes in tertiary education, based on students' cognitive and physiological behavior. Eight management students with varying academic backgrounds were selected through purposive sampling for the experiment which consists of active and passive learning sessions. The lecture served as the passive learning session. Problem-Based Learning (PBL) activities were conducted both individually and in groups, with another group activity following the lecture, representing the active learning sessions. Brain activity was measured using electroencephalogram (EEG) to identify Beta (β) waves. Physiological

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data was collected using a Galvanic Skin Response (GSR) sensor to measure sweat gland activity. Additionally, fluctuation in heart rate variation was captured through Electrocardiogram (ECG) signals. Exploratory data analysis was employed to analyse the bio-signal data. The group activity after the lecture resulted in the highest levels of cognitive and physiological engagement among participants. While students performed better in active learning sessions overall, individual activities were less effective compared to group-based activities. This study suggests that even though passive learning, like lectures, may have some value, a combination of passive and active learning strategies may yield the most productive learning environment for small group management courses in tertiary education.

Keywords: *Cognitive and Physiological behavior, Teaching methods, Active learning, Passive learning*

Introduction

Education is the process of investing in human capital to facilitate learning and drive a country's development. Teachers are the cornerstone of education, facilitating learning interactions that drive a country's development. Several platforms exist to conduct educational activities, including online platforms, traditional face-to-face methods, and blended approaches (University Grants Commission, 2021). Face-to-face teaching can be categorized into large-group and small-group instruction. When it comes to online learning platforms, synchronous and asynchronous teaching methods can be utilized as shown in Figure 1 (Amiti, 2020).

Different kinds of teaching methods, categorized as active and passive learning techniques based on student involvement (Mahmood et al., 2011), are used to conduct the education process in face-to-face and online platforms. The most popular teaching methods in face-to-face teaching and online teaching are mentioned in Table 1, except lecturing. Problem-based learning, for example, has proven to be one of the most successful and innovative methods for engineering education (De Graaf, 2003).

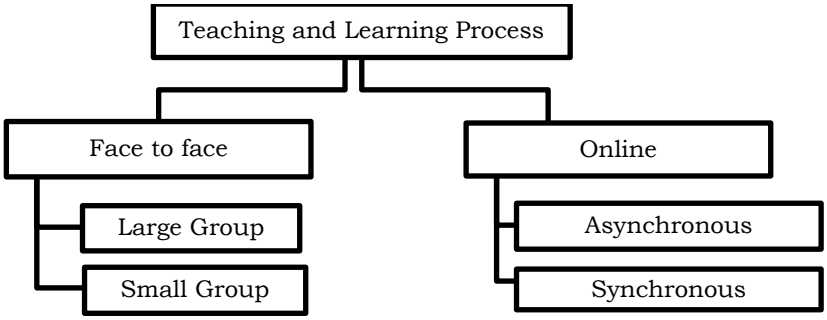

Figure 1. Different learning approaches

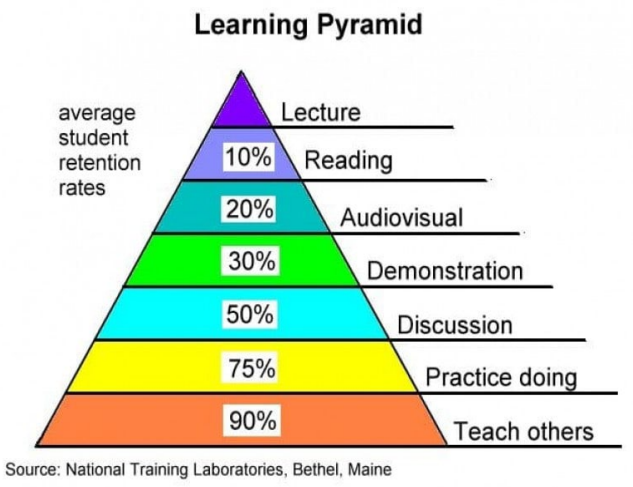

Figure 2. Learning Pyramid

Table 1. *Learning Methods*

Face-to-face teaching		**Online teaching**	
Small Group	**Large Group**	**Synchronous**	**Asynchronous**
Case Studies	Line-up	Instant Messaging	Audio/Video
Post It Parade	Post It Parade	Video and audio confer.	E-mail
Group Text Reading	Debates	Live webcasting	Discussion forum
Peer Review	Snowball	Application sharing	Wiki/Blog
Pro-Con Grids	Fishbowl	Whiteboard	Webcasting/Confer.
Buzz Groups	Index Card Pass	polling	
Think Aloud	Think-Pair-Share	virtual classrooms	
Round Table	Buzz Groups		
Debates	1-Minute Paper		

Selecting the ideal teaching method is crucial for maximizing the learning process's effectiveness. Traditional lectures, as shown in Figure 2 (Letrud, 2012), often lead to low knowledge retention rates. Therefore, identifying the most suitable teaching methods for different situations is essential.

However, choosing the right teaching method can be challenging. Teachers may select platforms based on resource availability without proper analysis, and even with diverse learning mechanisms within each platform. Research suggests that some students resist active learning strategies, favoring traditional methods (Henderson & Dancy,

2007; Fagen et al., 2002). Additionally, negative student feedback can lead instructors to abandon active methods for passive lectures (Henderson et al., 2012). With thousands of methods available on each platform, and the impact varying based on student level, class size, and teacher characteristics (Ehrenberg, 2001), identifying the ideal method can be overwhelming. Tailoring learning methods to specific categories is key to optimizing learning outcomes.

Traditionally, educators have relied on learner feedback (Theall & Franklin, 2001) such as peer review, self-evaluation, teaching portfolios, and student achievement to assess learning effectiveness (Sajjad, 2010). However, recent research by Aprielieva et al. (2021) suggests that analyzing students' cognitive and physiological factors can provide a more effective way to identify the ideal learning method. By understanding a student's cognitive and physiological behavior, educators can gain valuable insights into how students best acquire knowledge, develop skills, and process educational information. This shift towards analyzing cognitive and physiological factors holds significant promise for enhancing the learning experience and improving educational outcomes.

Thus, this study aims to identify the most suitable learning methods for tertiary education in the management discipline for small face-to-face classes through the cognitive and physiological behavior of the students.

Literature Review

Effective Teaching Methods

The rapid advancement of technology has ushered in a wave of intelligent teaching systems and diverse teaching methods. While lecturing remains a prevalent approach due to its practicality for large groups with limited resources (Alaagib et al., 2019), some argue it may not be the most effective due to low knowledge retention rates.

PBL motivates students to learn by themselves. It encourages active and self-directed learning. Independent learning, teamwork, and communication skills are enhanced with these PBL sessions. The students who are practicing PBL become better problem solvers (Foo et al., 2021).

Teachers and curriculum developers are struggling to identify the best

teaching method and ultimately students may not receive the learning content properly. Therefore, it is important to identify effective teaching methods for each category since the productivity of the session may vary with the student's education level, class size, and characteristics of the teacher, etc. (Ehrenberg, 2001).

The management discipline is selected in tertiary education and a small class in the face-to-face learning style is considered in this study for the consideration of resource availability. The PBL methods (active learning session), lectures (passive learning session), and mixing both lectures and PBL are considered learning sessions in this study to identify the best learning method.

Table 2. *Evaluation Methods to Identify Effective Teaching Methods*

Evaluation Methods	Authors
Peer review, self-evaluation, teaching portfolios, student achievement, and students 'ratings of teaching methods were used to evaluate the teaching effectiveness of the different teaching methods at the higher education level.	Sajjad, 2010
Identify the effective teaching method by analyzing the emotion of the students through facial expressions such as fear, disgust, surprise, sadness, anger, and neutrality.	Ramos et al., 2020
The questionnaire was used by the researchers to identify effective teaching methods for large classes with obtaining the response of the students.	Carpenter, 2006
The questionnaire was used to assess the use of language learning strategies	Oxford, 1996
Effective foreign language teaching and learning are identified through a questionnaire	Bell, 2005
Questionnaires are widely employed in medical education research.	Artino et al., 2014

Procedure to Identify the most Effective Teaching Method

Teachers and students are central figures in the education process. The evaluation of the teaching method can be done based on the comments/ideas/performance/outcome of the students and teacher. Different kinds of measurements are used by the researchers to identify the most effective teaching method according to their platform. The summary of the tools used by the researchers has mentioned in Table 2.

Traditionally, researchers have relied heavily on student feedback through questionnaires to assess the effectiveness of teaching methods (Lindemann, 2024). However, questionnaires may not always capture students' true feelings and emotions about their learning experience. Some researchers have explored alternative methods, as shown in Table 3, which involve analyzing student visuals and emotions to gain deeper insights.

The performance of the student is the best way to measure the effectiveness of the teaching pedagogy since the output is the most important component of any process including education. Academic performance and cognitive performance can be used to measure the performance of the students. Academic performance can be measured easily at the end of the learning session by the teacher. Cognitive performance can be measured through emotional intelligence. The stress level is an indicator of emotion (Abdullah & Hassan, 2012). Stress levels can be a valuable indicator of emotional response (Abdullah & Hassan, 2012). Bio-signals, such as those studied by Haouij (2018), can be used to assess these stress levels. However, researchers utilizing bio-signals throughout the learning session to explore how they relate to teaching effectiveness remain scarce (Handri et al., 2010).

According to the literature, most of the researchers used different types of written responses to measure the effectiveness of the teaching pedagogy at the end of the learning session. Even though the cognitive and physiological response is more reliable, very few researchers used one or a few bio signals throughout the session to identify effective teaching methods.

Cognitive and Physiological Measurements

The use of biosensors to detect emotions has gained significant traction in recent years. These sensors monitor physiological and cognitive signals generated by the autonomic nervous system, which offers a distinct advantage - it operates unconsciously, providing researchers with reliable, objective data (Jang et al., 2013).

The human brain is a complex network of neurons that communicate through electrical impulses. These electrical activities can be measured and analyzed as brainwaves, providing valuable insights into cognitive function. Electroencephalogram (EEG) is the most common tool used to record brainwaves (Nunez, 2000; Laufs et al., 2003). By analyzing the patterns of brainwaves, researchers can gain understanding of emotions, thoughts, and behaviors. Furthermore, brainwave patterns change based on a person's level of consciousness and cognitive processing (Brain Waves - GoodTherapy.org Therapy Blog, 2016). There are four categories of these brainwaves, Gamma (γ), Beta (β), Alpha (α), and Delta (δ). Among those different types of brain waves, Beta waves are very important for education since they are looking for focus, concentration, and analytical thinking (Arnaud, 2022).

In the context of education, Beta waves hold particular significance. This study will specifically focus on Beta wave to assess student engagement and concentration during different learning methods.

The autonomic nervous system plays a crucial role in regulating human physiological responses. When this system is stimulated, sweat gland activity increases, leading to higher skin conductance values detected by the GSR sensor (Hareendran, 2023). These GSR values can be interpreted as indicators of emotional arousal, providing insights into student engagement during learning.

A student's learning effectiveness is influenced by factors like cognitive load and working memory (Xiong et al., 2020). Fluctuations in physiological measurements, such as heart rate and galvanic skin response (GSR), can provide valuable insights into a learner's cognitive state (Cranford et al., 2014). For example, research by Webster (2005) and Bar et al. (2010) suggests that heart rate can vary depending on emotions and even music styles.

The analysis of brainwaves, GSR, and ECG values is important to

identify the productivity of the learning session based on the literature review. Identifying the effective teaching method based on the set of cognitive and physiological measurements of the student is the procedure of this study.

Methodology

This experiment investigated effective teaching methods in small management classes, focusing on students' cognitive and physiological characteristics. The small class consists of less than twenty-five students (Flaherty, 2020) and qualitative research studies typically reach a point of diminishing returns (saturation) after 10-15 observations (Mason, 2010). As an initial step, the research involved eight participants selected using the purposive sampling method. To ensure a representative sample, the students were selected for the experiment with varying academic performance levels and experience with both traditional and innovative teaching methods. Class engagement levels were also considered.

Table 3. *Activity Plan of the Experiment*

Activity	Time Duration
Preparation	10 minutes
Problem-based learning (Individual)	20 minutes
Problem-based learning (Group)	20 minutes
Lecture	20 minutes
Group Activity (Lecture)	20 minutes
Reposition	10 minutes

Table 4. *List of Biological Sensors*

Equipment	Purpose
• GSR Sensor	To measure sweat gland activity
• ECG sensor	To identify the electrical impulses through the heart muscle
• EEG Sensor	Detect the brain waves to identify the activities of the brain

The activities of the experiment are mentioned in Table 3. The introduction to the study was given at the beginning and explained the bio-medical items with the fixing mechanism. The problem-based learning sessions were conducted as the first sessions. The participants solve the problem individually and then they identify the solution for the different questions as a group activity. A small break was given after each session. The lecture session was conducted as the third session and again group activity was conducted based on the lecture as the last session. Around twenty minutes were allocated to each learning session.

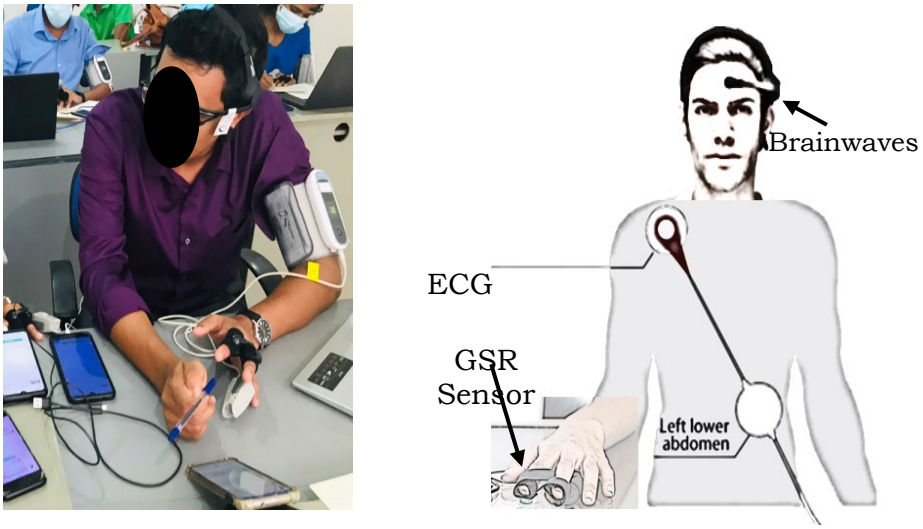

Figure 3. Participants of the experiment with the equipment

The study recruited eight participants (four male and four female) enrolled in the final year of a management program at a tertiary education institution in Sri Lanka. The participants' ages ranged from 22 to 24 years. All participants had prior experience with both active and passive learning methods. To ensure eligibility, participants were screened for any pre-existing reading disabilities, learning disorders, or attention difficulties. Additionally, all participants had normal or corrected-to-normal vision. The experiment was conducted in a small lecture room during a regular class period, and all participants underwent the same experimental conditions. The ethical approval for this study was granted by the Wayamba University of Sri Lanka's ethical committee.

At the beginning of the experiment, participants received detailed instructions about the procedures and the purpose of the study. Researchers then attached bio-sensor equipment to collect cognitive and physiological data during the learning sessions. Table 4 provides details about the specific equipment used and their purposes. As illustrated in Figure 3, participants were seated at individual desks facing computer monitors and keyboards throughout the experiment. Figure 3 can also be referenced for details regarding the placement of bio-sensor equipment on the participants. Following data collection, exploratory data analysis methods are used to understand the relationships between the teaching methods and the students' cognitive and physiological responses. These analyses will include:

Table 5. *Average Brainwaves During the Sessions*

Session	Brainwaves (Beta Values)
Problem-based learning (Individual)	19155.08
Problem-based learning (Group)	27047.06
Lecture	20094.34
Group Activity	25854.65

Table 6. *Average GSR Value During the Sessions*

Session	Average GSR Value
Problem-based learning (Individual)	210.75
Problem-based learning (Group)	182.35
Lecture	189.12
Group Activity	218.42

EEG Analysis: Brainwave data is preprocessed to remove noise and artifacts. Then, we will analyze the power spectrum within specific frequency bands (e.g., Beta waves associated with concentration) to assess changes in brain activity during different learning sessions.

GSR Analysis: Analyze GSR data to identify fluctuations in skin conductance, which can be indicative of emotional arousal and engagement.

ECG Analysis: Heart rate variability derived from ECG data will be examined to explore potential links between learning methods and students' cognitive load and emotional states.

Results and Discussion

The brainwaves of the participants were captured during the sessions using EEG to analyze the pattern of electrical activity in the brain. Gamma, Beta (β), Alpha (α), and Delta (δ) waves were obtained, and Beta waves were chosen for analysis because they are associated with focus, concentration, and analytical thinking. The value of the beta waves increased with learning during explicit tasks (MIT News, 2017).

The Beta values of the participants of the experiment are shown in the first graph of Figure 4 and the average value of the brainwaves during the sessions is mentioned in Table 5. A higher number of peaks can be identified during the group activities in both sessions compared to the other two sessions. The lowest values can be seen during the individual activity of problem-based learning and the lecture session. The result of the brainwaves indicates that the students gave more focus during the group activity of PBL since higher values of the brainwaves are captured during the group activities and many variations. The group activity of PBL is ranked as the best session based on EEG data analysis. Group activity after the lecture session and the lecture session was ranked as second and third places respectively based on the same characteristics.

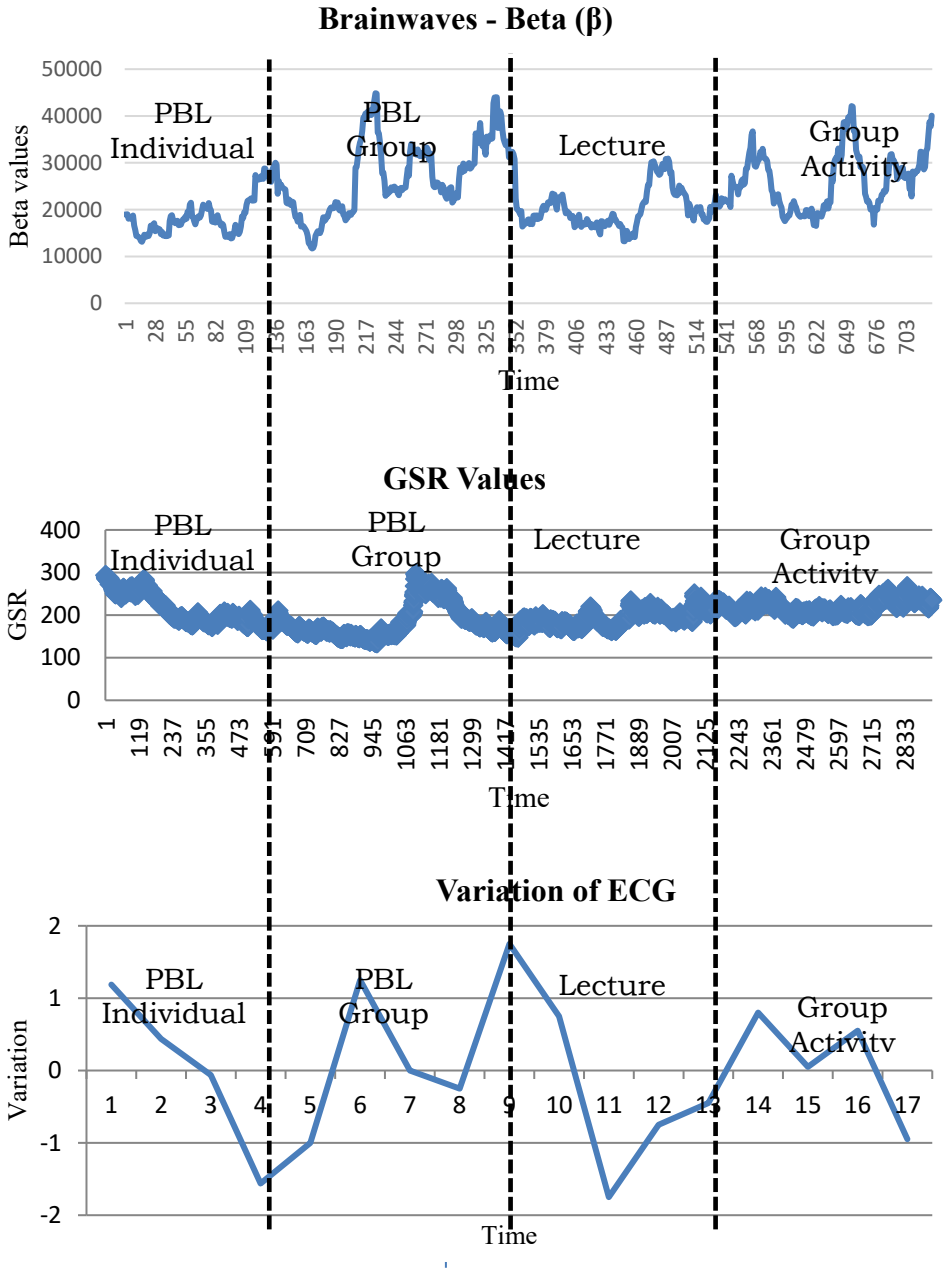

Figure 4. Analysis of the bio-signal data

Table 7. *Average Brainwaves During the Sessions*

Session	Heart rate variation
Problem-based learning (Individual)	Downward trend
Problem-based learning (Group)	Upward, the downward and upward trend
Lecture	Downward and upward trend
Group Activity	Upward, downward, upward, and the downward trend

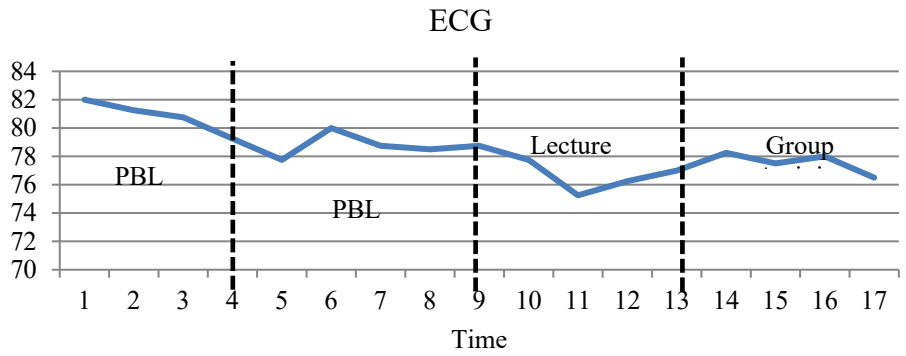

Figure 5. Analysis of ECG data

Table 8. *Average ECG Values During the Sessions*

Session	ECG Values
Problem-based learning (Individual)	80.81
Problem-based learning (Group)	78.75
Lecture	77.00
Group Activity	81.60

The GSR sensor measures the sweat gland of the participants, and the result is shown in the second graph of Figure 4. The average value of the session is mentioned in Table 6. The consistency and the

average level of GSR are mentioned during the energetic time of the participants (iMotions, 2023). The highest GSR value is mentioned during the group activity after the lecture and the lowest value is recorded in the group activity under the problem-based learning approach according to the average value. Even though many fluctuations can be identified during the group activity in problem-based learning, consistency can be seen in the group activity after the lecture. The highest average value and the consistency of GSR values indicate that the group activity after the lecture was the best session based on the GSR values. Even though the average GSR value is somewhat low, the consistency is high during the lecture session. Thus, the lecture is ranked second according to the GSR value. The individual activity of PBL was ranked as the fourth one since significant peak values and lowest average GSR values appeared during the group activity of PBL.

The heart rate variation of the students in this experiment is shown in the third graph of Figure 4 and Table 7. The higher heart rate variation is linked with better cognitive performance (Forte, 2019). The average ECG values of participants during the sessions are mentioned in Figure 5 and Table 8. A significant variation in heart rate is identified during the group activities and especially after the lecture session with the higher average ECG value. Only a downward trend can be identified during individual work in problem-based learning sessions. Group activities were ranked in the first two places and the individual activity of PBL was placed in last place based on the ECG values.

The summary of the findings is shown in Table 9. Each session is ranked based on its performance by considering three measurements (brainwaves, GSR values, and ECG values). The analysis of the brainwaves indicates that group activities are much more effective than lecture and individual activities. The lecture session and the following group activity are better than problem-based learning according to the GSR values. The variation of the heart rate values is identified with the ECG and it indicates that group activities are better than lectures and individual work. The group activities are the best ways to conduct the learning sessions according to the ranks of Table 9. The group activity after the lecture is the best session and the group activity in problem-based learning is the next best session of this

study. The lecture session and individual learning session are not very effective. Group activities are more effective than individual work and if the group activity is conducted after the discussion session, a higher level of efficiency can be achieved.

Table 9. *The Performance of the Sessions*

	Brainwaves	**GSR**	**ECG**	**Total Marks**	**Final Rank**
Problem-based learning (Individual)	4	3	4	11	4
Problem-based learning (Group)	1	4	2	7	2
Lecture	3	2	3	8	3
Group Activity (After Lecture)	2	1	1	4	1

Conclusions

The field of education, like many others, is constantly evolving with new technologies, methods, and mechanisms being introduced. However, implementing these advancements without understanding their impact on the learning process can be detrimental, especially in education, a key area that shapes a nation's future. This study aims to identify the best learning strategies based on the cognitive and physiological characteristics of the students. Initially, individual and group activities were conducted under the problem-based learning approach. Then the lecture session and group activity based on the lecture were conducted. Students' Cognitive and physiological characteristics were identified through heart rate variation, brainwave analysis, and sweat glands values.

The group activities are more productive sessions in the management discipline for the small class than the other two sessions, lecture, and individual activity based on the behavior of the cognitive and physiological characteristics of the student. The group activity after the lecture session is the most ideal learning session. The lecture session is ranked in third place and individual activity is the least

productive session. Even though the active learning approach is more effective than passive learning, the individual activity of PBL that is categorized under the active learning approach was the least effective in this study.

This indicates that neither purely active nor purely passive methods are optimal. The mixing of both active and passive teaching methods and group activities after the lecture session is the most effective method to conduct the learning session in the management discipline for small face-to-face classes in tertiary education.

Limitations

Although there are thousands of teaching methods, this study focuses on categorizing them as active or passive. Some methods may not fit neatly into these categories and will be excluded from this analysis. Due to resource limitations, only eight participants were involved in this initial phase. Ideally, a larger sample size would be used in future experiments. This study employed a cross-sectional design. A longitudinal study would provide more accurate results for investigating changes over time.

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