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Association of Binaural Beats on Critical Thinking of STEM Students

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***Abstract*—** This study employed a quasi-experimental single-group pretest-posttest design to assess the critical thinking abilities of 23 Grade 12-STEM students from Juban National High School during the 2024-2025 academic year, prior to any intervention involving binaural beats. Utilizing the Watson-Glaser Critical Thinking Appraisal (WGCTA), the study aimed to determine students' baseline critical thinking skills across five identified aspects: evaluation of arguments, recognition of assumption, deduction, inference making, and interpretation. The pre-test results revealed that students generally exhibited low critical thinking performance across all aspects, with a notable portion consistently scoring in the "below average" and "well below average" ranges. This indicates a significant need for targeted educational interventions to enhance these fundamental skills among Grade 12-STEM students.

***Keywords*—** Auditory stimuli, Binaural Beats, Critical thinking, PISA, STEM Education.

I. INTRODUCTION

The Philippine education system implemented the K-12 Basic Education Program to foster 21st-century skills and align with international standards (Republic Act 10157). This reform introduced a spiral progression approach in subjects like Science, Technology, Engineering, and Mathematics (STEM), aiming to enhance critical thinking and prepare students for global competitiveness and better occupations (Orale & Sarmiento, 2016; Estonanto, 2017).

Despite these efforts, recent results from the Programme for International Student Assessment (PISA) in 2022 revealed that Filipino students scored among the lowest globally in creative thinking and problem-solving, placing the Philippines near the bottom among 64 countries (OECD, 2024; Servallos, 2024). Specifically, the Philippines scored an average of 14 points in creative thinking (OECD, 2024). While mathematics scores slightly improved, science scores dipped, remaining below the OECD average (Chi, 2023). PISA test questions assess critical thinking through components like interpretation, analysis, evaluation, inference, explanation, and self-regulation, highlighting a significant gap in these areas among Filipino students (OECD, 2024; Supiarmo et al., 2022).

Critical thinking (CT) is a vital 21st-century skill, recognized alongside creativity, decision-making, and problem-solving (The Global Scholars, 2021). Its modern roots trace back to John Dewey's "reflective thinking" (Dewey, 1933), later developed by Edward Glaser and Goodwin Watson in 1925, who emphasized evaluation of arguments, recognition of assumptions, deduction, inference making, and interpretation as key components (Zulmaulida et al., 2018). Research indicates that CT can be taught through various methods, including specialized programs or integration into academic courses (Al-Ghadouni, 2021; Funa et al., 2024).

One promising intervention to enhance CT is the use of binaural beats, an auditory illusion where the brain perceives a third tone from two slightly different frequencies played in separate ears (Oster, 1973; Boje, 2024). First described by Heinrich Wilhelm Dove in 1839, scientific interest was rekindled by Gerald Oster in 1973, highlighting their potential for cognitive enhancement (Lemay, 2024). Binaural beats are believed to influence brainwave patterns, with specific frequencies linked to relaxation, focus, and problem-solving (Fishman, 2023). Beta waves (13-30 Hz) are particularly associated with active engagement, concentration, logical reasoning, and critical thinking (Moore, 2024).

While research suggests that binaural beats can positively influence cognitive performance, especially beta frequencies for memory and working memory (Garcia-Argibay et al., 2017; Kraus & Purovanova, 2015), some studies show mixed results regarding their direct influence on learning and memory (Beckam, 2025). Nevertheless, binaural beats are thought to enhance concentration and attention, which are crucial for effective learning (Beckam, 2025). Integrating binaural beats into STEM education could potentially boost innovation and student support by influencing

brainwave patterns and cognitive flexibility (Hommel et al., 2016; Gonzalez et al., 2021).

The current study aims to determine the association of binaural beats on critical thinking among Grade 12 STEM students at Juban National High School for the academic year 2024-2025. Specifically, it seeks to: 1) Determine students' critical thinking skills prior to binaural beat incorporation across five aspects: a) evaluation of arguments; b) recognition of assumption; c) deduction; d) inference making; and e) interpretation.

II. METHODOLOGY

Research Design

This study employed a quasi-experimental single-group pretest-posttest design. This approach allowed for the measurement of participants' critical thinking skills before any intervention. The pretest served as a crucial baseline to assess the students' initial critical thinking abilities, providing a foundation for understanding their proficiency in this area prior to any potential influence.

Participants

The participants of the study are the Grade 12 STEM senior high school students of Juban National High School, from the Division of Sorsogon Province for the academic year 2024-2025. The researcher intentionally selected 12-STEM class which is composed of 23 students to be the participants as this class represents the whole population of STEM students of the school as it only has one Grade 12-STEM class, making them the most suitable candidates for the research. The researcher decided to utilize purposive sampling, ensuring the chosen participants are aligned with the research objectives. Among the respondents, six, or 26% are male and 17 or 74% are female.

Research Ethics

The confidentiality of all respondents' information was rigorously ensured and fully complied with. The researcher prioritized the implementation of personal data privacy, clearly informing participants of their right to exclude any identifying details and their option to withdraw voluntarily at any point.

All respondents were thoroughly briefed on the collection, usage, storage, and protection protocols for their information before their involvement. The data gathered was exclusively used for the specific purposes outlined in the research proposal, thereby upholding all ethical guidelines and guaranteeing the privacy and rights of every participant involved in the study.

Research Instrument

The primary research instrument for this study involved the strategic incorporation of binaural beats. Specifically, beta binaural beats, within a frequency range of 13 to 30 Hz, were utilized to investigate their potential association with various facets of critical thinking. Binaural beats are a unique psychoacoustic phenomenon where the human brain, when presented with two slightly different pure tones simultaneously in separate ears (typically via headphones), perceives the creation of a distinct third tone. This perceived tone's frequency is equivalent to the difference between the two input frequencies and is often described as being localized within the head, or between the ears.

Complementing the binaural beats, a standardized and globally recognized critical thinking assessment, the Watson-Glaser Critical Thinking Appraisal (WGCTA), was employed to gather quantitative data for both the pre-test and post-test phases of the study. Developed by Goodwin Watson and Edward Glaser, the WGCTA is lauded for its ability to quickly, consistently, and accurately measure an individual's capacity to analyze, reason, interpret, and logically conclude from written information. Tailored for individuals aged 16 and above (Pearson, 2017), the WGCTA comprises 86 meticulously structured questions. These questions vary in difficulty and format to comprehensively assess five core aspects of critical thinking, each requiring distinct, though interdependent, applications of analytical reasoning. These aspects include the evaluation of arguments, recognition of assumptions, deduction, the skill of making inferences, and finally, interpretation.

The WGCTA has consistently demonstrated robust construct validity, affirming its effectiveness in assessing critical thinking as intended (Hassan & Madhum, 2006). Validation studies, including those on university students in Lebanon, have reported significant correlations with various criterion measures, thereby providing strong evidence of its convergent and divergent validities. Furthermore, exploratory factor analysis has consistently revealed a unidimensional factor structure, reinforcing the test's construct validity (Hassan & Madhum, 2006). The WGCTA's ability to effectively differentiate between groups based on educational level and field of study further solidifies its validity (Aslan et al., 2019), with observable significant score differences among senior students from diverse academic streams. Beyond its validity, the WGCTA has consistently exhibited high reliability, evidenced by numerous studies reporting strong internal consistency

(Hassan & Madhum, 2006). Specifically, Cronbach's alpha coefficients for its various subtests have consistently exceeded the acceptable threshold of 0.70, indicating that the test reliably produces stable results (Hassan & Madhum, 2006). Additional research, such as a study involving Turkish university students, has further supported the instrument's robustness by confirming satisfactory reliability coefficients for its short form (Aslan et al., 2019).

The WGCTA's proven capacity to yield consistent results across varied populations, including psychology majors and nursing students, strongly underscores its overall reliability in accurately measuring critical thinking skills (Hassan & Madhum, 2006).

Data Collection

The primary research instrument in this study involved the strategic incorporation of binaural beats. Specifically, beta binaural beats, operating within a frequency range of 13 to 30 Hz, were employed to investigate their potential association with various facets of critical thinking.

This method leverages the psychoacoustic phenomenon where the human brain perceives a distinct third tone when presented with two slightly different pure tones simultaneously in separate ears (typically via headphones).

The frequency of this perceived tone is equivalent to the difference between the two input frequencies, and its localization is often described as being within the head or between the ears.

Complementing the binaural beats, the Watson-Glaser Critical Thinking Appraisal (WGCTA) served as the standardized assessment tool for gathering quantitative data during both the pre-test and post-test phases of the study. Developed by Goodwin Watson and Edward Glaser, the WGCTA is globally recognized for its efficacy and reliability in evaluating critical thinking skills. Designed for adults aged 16 and above (Pearson, 2017), this 86-question instrument meticulously measures an individual's capacity to analyze, reason, interpret, and draw logical conclusions from written information. The WGCTA's comprehensive structure covers five core aspects of critical thinking: evaluating arguments, recognizing assumptions, deduction, making inferences, and interpretation. The instrument's strong construct validity has been consistently demonstrated, showing its effectiveness in assessing critical thinking as intended through significant correlations with various criterion measures and a unidimensional factor structure (Hassan & Madhum, 2006). Furthermore, its reliability is well-established, with Cronbach's alpha coefficients consistently exceeding 0.70, indicating stable and consistent results across diverse populations and academic contexts (Hassan & Madhum, 2006; Aslan et al., 2019).

Data Analysis

The data from the pre-test were summarized using descriptive statistics, specifically the percentile rank of students' score for each aspect of CT were computed representing student's critical thinking performance prior to the incorporation of binaural beats which was interpreted using the adopted scale from Pearson (2017). This descriptive statistic is important as raw scores can only be used to rank test takers, but can't tell anything else.

The scale for determining students' critical thinking performance categorizes percentiles into five distinct ranks which indicates whether students have scored low or high for both pre and post-test along the following aspects of critical thinking:

Range	Description
91st percentile and above	"A" "Well above average"
71st to 90th percentile	"B" "Above average"
31st to 70th percentile	"C" "Average"
11th to 30th percentile	"D" "Below average"
10th percentile and below	"E" "Well below average"

III. RESULTS

This section reveals students' pre-test performance in the Watson Glaser critical thinking Appraisal along the following aspects of critical thinking. Critical thinking as defined by Winifred Watson and Edward Glaser refers to the ability of an individual to think clearly and rationally maintaining the capacity to reason logically and establish connections between concepts.

Each table presents the percentile ranks, frequencies, and its description based on the student's percentile ranking scores' interpretations.

Table 1: Pre-test performance for Arguments based on Percentile Rank (N=23)

Percentile Rank	Frequency	%	Description
91st and above	1	4.35%	Well above average
71st - 90th	6	26.09%	Above average
31st - 70th	8	34.78%	Average
11th - 30th	5	21.74%	Below average
10th and below	3	13.04%	Well below average

Table 1 presents the pre-test performance result for evaluation of arguments. The table shows a mixed performance among students, with a small subset scoring in the "well below average" range. Specifically, percentile rank revealed that three students (13.04%) faced learning difficulties. Additionally, a notable number of students scored in the "below average" category with five or approximately 21.74% of the students placed in this range. Meanwhile, a larger number of the participants at eight (34.78%) falls within the "average" level.

Meanwhile, students achieving a bit higher score than the median demonstrate "Above average" performance, comprising of six students. Moreover, only one student reached "well above average" category.

Table 2: Pre-test performance for Assumption based on Percentile Rank (N=23)

Percentile Rank	Frequency	%	Description
91st and above	3	13.04%	Well above average
71st - 90th	3	13.04%	Above average
31st - 70th	12	52.17%	Average
11th - 30th	4	17.39%	Below average
10th and below	1	4.35%	Well below average

Table 2 presents the pre-test performance for recognizing assumptions based on their percentile rankings which illustrates a diverse range of scores across various performance categories. The table revealed that only one student from the group obtained the "well below average" category. Additionally, the "below average" groups were consisting of four students (17.39%). This result indicates that only a total of five students (21.74%) performed below the average level suggesting that only a small portion of the participants struggled significantly with the skill of recognizing assumptions. Meanwhile, around half of the participants achieved the "average" range with twelve students (52.17%) scoring in this level, indicating a satisfactory level of understanding among the group. As for the "above average" category, data shows that three students about 13% of the total achieved this level of proficiency. Finally, the table also revealed that three students were able to be at the "well above average" range.

Table 3: Pre-test performance for Deduction based on Percentile Rank (N=23)

Percentile Rank	Frequency	%	Description
91st and above	4	17.39%	Well above average
71st - 90th	2	8.70%	Above average
31st - 70th	10	43.48%	Average
11th - 30th	5	21.74%	Below average
10th and below	2	8.70%	Well below average

Table 3 provides insights into the pre-test performance of participants specifically in the area of deduction, as measured by their percentile ranks. The data indicates a notable challenge for a significant portion of the student body, with seven students, representing 30.43% of the total, scoring in the "well below average" and "below average" categories. This suggests that a substantial number of individuals were struggling with their deductive reasoning skills at the outset of the study. Conversely, nearly half of the participants, specifically 10 students (43.48%), achieved scores within the "average" range, indicating a foundational, albeit not excelling, understanding of deductive principles. Furthermore, while two students demonstrated "above

average" performance, a limited number of high achievers were observed, with only four students (17.39%) reaching the "well above average" percentile. This distribution highlights a critical need for targeted instructional strategies that can both support those struggling with deduction and provide sufficient challenge and opportunities for advanced development for those who possess foundational understanding or higher potential.

Table 4: *Pre-test performance for Inferences based on Percentile Rank (N=23)*

Percentile Rank	Frequency	%	Description
91st and above	3	13.04%	Well above average
71st - 90th	1	4.35%	Above average
31st - 70th	13	56.52%	Average
11th - 30th	4	17.39%	Below average
10th and below	2	8.70%	Well below average

Table 4 presents the pre-test performance for making inferences. The distribution of scores reveals a range of performance levels across different categories. In the "well below average" category, only two students (8.70%) from the group scored at this level. Additionally, four students fall into the "below average" category. This indicate that a total of six students or around 26.09% of the group scored below the average level. Meanwhile, a substantial portion of the students, comprising more than half of the class falls within the "average" range with 13 students, approximately 56.52%. This indicates moderate level of understanding among the participants. Moreover, in the higher performance categories, one students' score demonstrates an "above average" understanding, while three students scored in the "well above average" range.

This indicates that only a small number of students excel in making inferences. Overall, the data illustrates varied performance levels, highlighting both challenges faced by some students and presence of high achievers within the group.

Table 5: *Pre-test performance for Interpretation based on Percentile Rank (N=23)*

Percentile Rank	Frequency	%	Description
91st and above	1	4.35%	Well above average
71st - 90th	5	21.74%	Above average
31st - 70th	13	56.52%	Average
11th - 30th	3	13.04%	Below average
10th and below	1	4.35%	Well below average

Table 5 shows the pre-test performance for interpretation among 23 students highlighting a range of scores that reflect varying levels of understanding. In the lower levels, "well below average" category was achieved by a single participant scored at this level while three students from the group scored in the "below average" range. This indicates that a small group of students encountered significant challenges with the interpretation skills. As for the" average" category, this were achieved by thirteen students approximately at 56.52% of the total population. This suggests that a majority of students possess a foundational understanding of interpretation skill. However, the higher performance categories revealed that five students scored "above average", and only one from the group achieved the "well above average" range. This limited number of high achievers underscores a disparity in performance, with many students demonstrating average skills while only a few excel significantly in interpretation.

Table 6: *Summary of students' pre-test performance along the identified aspects of critical thinking (N=23)*

Aspects of CT	Well above average (%)	Above Average (%)	Average (%)	Below average (%)	Well below average (%)
Arguments	4.35	26.09	34.78	21.74	13.04
Assumption	13.04	13.04	52.17	17.39	4.35
Deduction	17.39	8.70	43.48	21.74	8.70

Inferences	13.04	4.35	56.52	17.39	8.70
Interpretation	4.35	21.74	56.52	13.04	4.35

Table 6 summarizes the pre-test performance results for 23 students across various aspects of CT which provide valuable insights. The scores for each aspect, categorized into five performance levels: "well above average", "above average", "average", "below average", and, "well below average". This categorization allows for a clearer understanding of students' strengths and weaknesses in critical thinking. The distribution of scores reveals a diverse range of CT skills among students. A small number of students achieved "well above average" or "above average" scores, indicating that these individuals possess a strong grasp of CT concepts. In contrast, a significant number of students fell into the "average" category, suggesting a foundational understanding of the material. Additionally, a notable portion of the group scores, "below average" or "well below average," indicating areas where many students face challenges in CT abilities among students, illustrating the spectrum of skills present within the group. Overall, the results reflect the complexity of CT skills and the diverse capabilities of the student population.

IV. DISCUSSION

With the recent Programme for International Student Assessment (PISA) result showing low scores for the Philippines, it did provide valuable insights into the capabilities of the students from the country in critical thinking and problem-solving skills (OECD, 2024). These skills, specifically, critical thinking are increasingly vital in our complex, interconnected world and the key findings revealed a pressing need to improve the country's' education policy, and pinpoints the importance of cultivating critical thinking skills in students, especially in the field of Science, Technology, Engineering, and Mathematics areas of education. The implications of these findings for education policy are profound. As the Philippines underwent reform to K-12 curriculum, it aimed to align the education system standard internationally, yet, the recent PISA result implicates to strongly integrate critical thinking and problem-solving skills across all subjects (OECD, 2024). Such reforms would ensure that students not only acquire knowledge but also learn to apply it effectively in various contexts. As global challenges continue to evolve, equipping students with the skills to think critically and solve problems will be paramount towards achieving next generations critical thinkers that are capable of analyzing information and making informed decisions that positively impact society.

A recent study by Benedicto and Andrade (2022) reinforces the idea that K-12 educational reform still hasn't achieve great results on improving Filipino students critical thinking ability. The Study stated that despite the implementation of educational reforms such as the K-12 program that aims to enhance the quality of education, challenges remain. Additionally, reports also indicate that the reforms have not yet translated into significant improvements in students' critical thinking skills. The focus on standardized testing and curriculum coverage often detracts from opportunities for students to engage in critical analysis and problem-solving. This result also aligns with the findings of De Leon (2023), which revealed that while the K-12 curriculum aimed to implement a learner-centered approach, the application was inconsistent leading to a lack of engagement and analytical skills among students. This statement has been confirmed for this study was based on the pretest results, it revealed that the distribution pattern for the five identified aspects of CT proves that students struggle within each aspect as shown in the percentile rank calculations revealing moderate to high percentages of STEM responding students underperformed getting mostly "below average" and "well below average" scores. This indicates the necessity of specific intervention strategies to aid underperforming students and increase the academic goals for those in the average range to help bridge achievement gaps together.

For the aspect of evaluating arguments, the initial assessment demonstrated wide individual differences among the participants. The result highlights a significant need for targeted interventions, particularly for the 34.78% of student scoring in the "well below average" and "below average" range. Moreover, the limited number of students achieving "well above average" scores indicates that the students may have struggled in comprehension and focus for evaluating the arguments presented. To address these challenges, educational interventions should be implemented to assist participants who are underperforming.

On the aspect of recognizing assumption, pre-test percentile ranking showed different degrees of understanding. Data demonstrates a significant need for

targeted interventions, particularly among the 21.74% struggling in the "well below average" and "below average" category. Additionally, the presence of students' other categories such as in the "average" category which is comprised of around half of the participants at 52.17% suggests that differentiated instruction is still necessary to address varying levels of proficiency and improve. Meanwhile, the moderate achievements in the "above average" group indicate opportunities for enrichment activities, while single "well above average" scorer underscores the potential for advanced learning experiences. Overall, theses insights emphasize the need for intervention as students evidently struggled. Developing students' skills in recognizing assumptions through various interventions could help bridge knowledge gaps and improve assumption skills for the participants.

Moving on with the third aspect, deduction, the data demonstrated various results with scores between 5 and 15 among the 23 respondents. With a substantial portion scoring in the "well below average" and "below average" categories, it is clear that many students were struggling with this skill. For the "average" category, it was revealed that 10 participants or approximately 43.48% of the population achieved this level indicating that almost half of the students have baseline understanding for this aspect of CT, however, the limited numbers of students reaching "above average" and "well above average" scores suggest a lack of high achievers in the group. This indicates a critical need for instructional strategies and interventions that does not only support struggling students but also challenge those who have the potential for higher achievement. With this aspect getting almost half of the participants at average score at 43.48% of the population, this still highlights a concerning trend as approximately 30.43% obtained lower scores, this suggests a good number of individuals need further help with this aspect of CT. The result indicates that specific educational strategies must be implemented to boost deduction comprehension leading to complete learning achievement among participants.

For inferences, the pre-test percentile scores obtained from 23 participants display crucial information about their achievement levels. Results indicate that around 26.09% of the students obtained lower scores scoring below the average. This low performance raises concerns since a large number of students show poor performance during this assessment. Despite some students reaching average levels at 47.83%, still, most participants demonstrated limited progress because only at around 17.39% of the population performed above the average level in the examination, highlighting a lack of advanced comprehension skills among participants. In connection to this, the findings of Ingendoh et al. (2023) described in their systematic review varying results between binaural beats and cognitive performance highlighting that there is inconsistency in the empirical outcomes regarding binaural beats and its effects on cognitive functions including inferencing.

Lastly, for the aspect of interpretation, the result showed that over half of the participants achieved scores within the average range at approximately 56.52%. Meanwhile, while many students achieved average level, still 17.39% of the participants received marks below the average which suggests several test-takers require additional educational help. Moreover, the participants that scored above the average were at around 26.09% of the population. These findings show a requirement for specific intervention programs to assist students who got scores below average on the pre-test assessment. The improvement of overall interpretation skills requires expert attention to the participants who need additional help. Educational approaches customized for individual needs will provide success opportunities to all students.

Furthermore, Ingendoh et al. (2023) emphasize the potential of binaural beats to enhance cognitive functions, suggesting that integrating such innovative methods could stimulate students' CT and problem-solving skills. This aligns with the findings that a substantial percentage of students who scored below average across various instruction to meet diverse learning needs and improved overall academic performance. In summary, this findings from the pre-test assessment highlights a critical need for targeted educational interventions to enhance students' critical thinking skills, as the overall pre-test result indicates that there was still a need to improve in students critical thinking abilities to meet the expectations set by DepEd, as outlined in the goals of K-12 education reform.

Despite the intention to improve educational outcomes, studies such as those by Benedicto and Andrade (2022) supports the studies result indicating that the implementation of learner-centered approaches has been inconsistent, resulting in limited engagement and analytical skills among students. The lack of significant improvements in CT abilities, as reported in these studies, underscores the necessity for specialized instructional strategies.

V. CONCLUSIONS AND RECOMMENDATIONS

The initial assessment of critical thinking skills, conducted through a pre-test prior to any intervention with binaural beats, revealed a clear and consistent pattern of low performance among the students. This was particularly evident across all evaluated aspects, including the ability to evaluate arguments, recognize assumptions, engage in deductive reasoning, make inferences, and interpret information. This widespread deficiency underscores a critical and urgent need for dedicated educational interventions to bolster these fundamental critical thinking skills.

In light of these findings, it is strongly recommended that educators implement targeted interventions specifically designed to address and improve the critical thinking abilities of Filipino students, especially in the areas identified as weak during the pre-test. These interventions should strategically integrate active learning techniques and carefully designed instructional strategies aimed at fostering a relaxed mental state. Such an approach is supported by the brainwave frequency theory and the brainwave entrainment hypothesis, both of which suggest that a calm and focused mental state can optimize student engagement and learning. Furthermore, by consciously applying principles from cognitive load theory, educators can reduce extraneous mental demands, thereby enabling students to more effectively allocate their cognitive resources to the complex processes involved in critical thinking. This holistic and theoretically informed approach is anticipated to create a more conducive and impactful learning environment, ultimately leading to significant improvements in students' capacities for argument evaluation, assumption identification, deductive reasoning, inference making, and interpretation.

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