An Evaluation of Synesthetic Learning Pedagogy for Engineering Education

[1]B M Bharath, [2]Naresh Kumar Sharma, [3]V. Lakshmi Narasimhan
[1]Undergraduate Student, Computer Science and Engineering
[2]Associate Professor, Biotechnology
[1 2]Kalasalingam Academy of Research and Education-Tamil Nadu, India
[3]Patterson Distinguished Professor
[3]Elizabeth City State University-NC, USA
[1]bharathbm83@gmail.com
[2]naresh@klu.ac.in
[3]srikar1008@gmail.com

Abstract— **This study explores how aural stimuli affect engineering education. It looks at their impact on learning, comprehension, and memory retention. The study focuses on two sets of engineering students: 30 studying enzymes and 60 studying wastewater treatment. It tests the impact of three auditory frequencies: 20 Hz, 40 Hz, and no music. The study uses a controlled experiment. It tests academic performance on the same day, and the third and seventh days after exposure. The results show that some frequencies, especially 40 Hz, boost cognitive function. They improve understanding and long-term memory. This study shows that auditory stimuli can improve traditional teaching. They do this by integrating multisensory learning techniques. It offers new ways to boost engineering education.**

Keywords— **Auditory Frequency, Auditory Stimuli, Cognitive Performance, Educational Pedagogy, Multisensory Learning, and Synesthetic Learning.**

ICTIEE* Track*: Pedagogy of Teaching Learning

ICTIEE Sub-Track: Integrative pedagogy – to bridge horizons and disciplines.

I. Introduction

Innovative teaching methods are being used to improve engineering education. They accommodate various learning styles and enhance standard teaching. One way to improve cognitive skills, like memory and focus, is to use auditory stimuli, especially music. Several studies have examined the impact of music on learning. They found that certain sound frequencies can greatly impact learning and thinking (Ramachandran & Hubbard, 2004; Janus et al., 2016).

Multisensory learning, which appeals to several senses at once, is now popular. It is seen as a way to boost academic performance. Research shows that multimodal environments improve students' retention and comprehension (Shams & Seitz, 2008; Esplendori et al., 2021). Esplendori et al. (2021) emphasize that, by using various senses in education, we can improve learning and cognition. Research shows that music can improve attention, affect emotions, and boost learning (Gaser & Schlaug, 2003; Llinás & Ribary, 1993).

Research on the use of audio stimuli as a learning aid in engineering education remains limited. A new study suggests that adding music to classrooms can help. It can improve students' focus, retention, and academic performance. For instance, auditory stimuli can promote more inclusive teaching. They can also boost student engagement. Newman (2018) discusses this. Taljaard (2016) examines how multisensory tech can boost learning in STEAM classrooms. It does this by engaging many senses. We want to know how different frequencies affect thinking. In particular, we want to see their impact on problem-solving and memory.

For example, Taljaard (2016) found that sounds can boost problem-solving in technical subjects. Newman (2018) noted that multisensory techniques might improve STEM learning. These studies support the growing interest in using sensory modalities to improve engineering education.

Klink (2020) studied tACS's effects on cognitive function at specific frequencies. It emphasized the potential for frequency-dependent effects on learning. Schellenberg (2005) examines how music affects cognitive functions, like memory. It shows that music can improve cognitive performance.

This research studies how sounds affect two groups of engineering students: 30 in an Enzyme course and 60 in a Biological Wastewater Treatment course. This study aims to

Dr Naresh Kumar Sharma
Associate Professor, Biotechnology, Kalasalingam Academy of Research and Education-Tamil Nadu, India
naresh@klu.ac.in

find the best sound for learning. It will test the effects of various music frequencies on different groups. Using various student groups allows a detailed study of how auditory stimuli could affect students differently, depending on the topic and learning environment.

Moreover, this research aims to add to the growing literature on synesthetic learning. It suggests that using multiple senses can improve learning (Lakshmi Narasimhan et al., 2020) . The research studies how to use music at specific frequencies. It aims to improve engineering course outcomes by enhancing the auditory aspect.

Neuroscience and educational psychology have researched how sounds can boost cognitive performance. Background music affects learning and memory. Results vary by music genre, study setting, and learners' traits. This study, conducted in a classroom, explores how different auditory conditions affect student learning. It tests three conditions: no music, 20 Hz music, and 40 Hz music.

No Music Condition: A common control in research is no music. It helps us understand learners' performance without outside sounds. Studies suggest that, without music, students might focus better on tough tasks. Less cognitive load could be the reason. An example is a study by Furnham & Strbac (2002). It found that students scored higher on tough tasks in a quiet place than while listening to music. This discovery suggests that, for deep thinking, no music may improve learning by reducing distractions.

20 Hz Music Condition: Low-frequency sounds, like 20 Hz music, can trigger deep relaxation and meditation. They align with the brain's delta waves, found in deep sleep. There is little research on 20 Hz music's impact on learning. Current studies suggest that it may decrease stress and encourage relaxation. This, in turn, could improve concentration. López-Caballero & Escera (2017) found that low-frequency noises may affect brain function. They may boost alpha and theta waves, which are linked to calmness and lower stress. The effect of 20 Hz music on learning is disputed. Some research suggests it may not boost mental functions. So, it may not improve educational results. [Smith & Lee, 2021; Williams & Robinson, 2022; Martinez et al., 2018].

40 Hz Music Condition: On the other hand, extensive research has been conducted on the potential cognitive advantages of 40 Hz music. This frequency is linked to brain gamma waves. They relate to advanced functions like memory, attention, and processing information . Studies show that 40 Hz music can boost memory and problem-solving. It does this by syncing brain waves in different brain areas. Buzsáki & Wang (2012) found that 40 Hz gamma oscillations are vital for perception, attention, and memory.

In addition, research conducted by Pritchett et al. (2008) examined gamma frequencies in various age brackets. They concluded that 40 Hz gamma activity is crucial for preserving cognitive abilities in all ages. Their studies stress the importance of gamma oscillations in cognitive skills. This is especially true for tasks that require focus and memory. This suggests that 40 Hz sounds, like music, may boost learning.

This study builds on that research. It investigates how three auditory conditions affect two student groups. One group studies Enzymes Technology (ET) and the other, Biological Wastewater Treatment (BWWT). This study aims to see if music gives a cognitive edge over other sounds. It will also explore how these benefits vary in different educational settings. It will use the Synesthetic Learning Pedagogy (SLP) methodology.

II. Literature Review

The literature surrounding the impact of auditory stimuli on cognitive functions, particularly in educational contexts, is limited and reveals a significant potential for enhancing learning outcomes through multisensory approaches. This section reviews relevant studies, focusing on the effects of auditory stimuli such as music on memory, attention, and learning, with a specific emphasis on engineering education.

A. Auditory stimuli and cognitive performance

The influence of auditory stimuli on cognitive performance has been widely studied. Research by Schellenberg (2005) indicates that background music can improve certain cognitive abilities, including spatial-temporal reasoning and memory. Likewise, Thompson, Schellenberg, and Husain (2001) discovered that music, specifically the "Mozart effect," can boost mood, leading to better cognitive performance in tasks that demand attention and memory. Peretz (2006) has strengthened the link between music and cognitive improvement by investigating how music affects brain function, indicating that music has the ability to activate parts of the brain related to memory and learning.

B. Synesthetic learning pedagogy

Synesthetic learning engages multiple senses at once. It may improve learning. Shams and Seitz (2008) highlight the benefits of multisensory learning. Using multiple senses helps students remember and use information better. Ramachandran and Hubbard (2004) examine the brain's role in synesthesia. They suggest that cross-sensory interactions can enhance learning. Newman (2018) supports using multiple sensory methods in inclusive teaching. Newman suggests that using various senses can help students. Adding visual, auditory, and tactile elements can improve learning. It will create a better environment. It will support students with different needs. They will understand complex ideas better and remember information longer.

C. Impact of music on learning in engineering education

Many studies have focused on how sounds affect cognitive function. But there is a growing body of research on its impact on engineering and STEM education. Newman stresses the need for multisensory methods. They are vital for creating inclusive, effective STEM learning environments. He stresses the need to use sound with other senses. This boosts students' engagement and understanding, making tough concepts easier.

Taljaard (2016) examined multisensory technologies in STEAM classrooms. It found that adding auditory cues can significantly enhance problem-solving skills and understanding.

Studies conducted by Klink et al. (2020) showed that frequency-specific sounds affect cognitive performance. It focused on tasks involving attention and memory. These results provide a basis for using these stimuli in engineering and other fields to improve learning. Taljaard (2016) cooroborated that these multisensory methods needs to be integrated into the curriculum to enhance the success. Poor use of multisensory strategies could instead overload them and hinder student learning.

In engineering education, synesthetic learning is an effective pedagogy. It addresses the field's unique challenges. Narasimhan et al. (2020) studied synesthetic learning in engineering classes. It found that using multiple senses, like hearing, made students more engaged. It also helped them remember difficult concepts better.

D. Comparison of music frequencies on learning

The effects on learning can stem from the music's frequencies. A 1993 study by Llinás and Ribary highlighted the importance of 40 Hz oscillations in cognitive functions. They promote synchronized brain states that support learning. Palva et al. (2005) found evidence of phase synchrony in neuronal oscillations in the human cortex. Their study showed that syncing brain waves to certain sound frequencies can improve focus and memory. Effective communication between various brain regions is essential for enhancing cognitive performance. Also, Gaser and Schlaug (2003) found that musicians, who hear organized sounds, have better brain structures linked to memory and learning. This supports the use of music as a cognitive aid in education.

E. Implications for educational practice

Using these discoveries in education shows that some sounds can improve results. Newman (2018) studied if multisensory methods could improve education. The goal was to make learning more inclusive. His work shows the importance of using different senses, like sound. It can boost students' engagement and understanding. Taljaard (2016) says that sound in STEAM classrooms can boost problem-solving skills and understanding. It stresses the need to add these methods to the curriculum for cognitive growth.

Research shows that auditory stimuli, especially music at certain frequencies, can boost learning-related cognitive functions, like memory and attention. Applying these discoveries to engineering education shows promise. Focusing on synesthetic learning techniques may boost student performance in tough classes. This research builds on that work. It examines how sounds affect two groups of engineering students. The goal is to better understand the role of multisensory learning in higher education.

III. METHODOLOGY

A. Participants

The research included 90 students from Kalasalingam University. It comprised 60 from a Biological Waste Water Treatment (BWWT) course and 30 from an Enzyme Technology (ET) course. The subjects were randomly assigned to three groups. This was based on the type of auditory stimulus they received during their learning sessions.

1) *No Music Group:* Students received no auditory stimulus during the learning sessions.
2) *Soft 20 Hz Music Group:* The instructor exposed students to soft 20 Hz music during the learning sessions.
3) *Hard 40 Hz Music Group:* The instructor exposed students to hard 40 Hz music during the learning sessions.

The participants ranged in age from 19 to 21 years, all enrolled in their second or third year of engineering programs. Potential confounding variables, such as prior exposure to similar auditory environments, were minimized by randomizing group assignments. The specific frequencies— NO Music, 20 Hz and 40 Hz—were chosen based on their associations with cognitive states: 20 Hz aligns with relaxation and delta waves, while 40 Hz is linked to gamma waves and higher-order cognitive processes

B. Experimental design

The study was conducted over a series of three different days:

1) *Same Day (Day 0):* The initial learning session and immediate post-learning assessment were conducted.
2) *Third Day (Day 3):* A follow-up learning session and assessment were conducted three days after the initial session.
3) *Seventh Day (Day 7):* The final learning session and assessment were conducted seven days after the initial session.

Each group received the same instructional material tailored to their respective subjects (Biological Wastewater Treatment or Enzyme Technology studies). The only variable was the type of auditory stimulus provided during the sessions. The student's performance was measured immediately after each session.

C. Data collection

Scores were collected for each student after every learning session (Day 0, Day 3, Day 7). The scores were based on assessments designed to measure the student's understanding and retention of the material.

1) *Enzyme Class Scores:* Collected from 30 students.
   No Music Scores: Data from students who received no auditory stimulus.
   Soft 20 Hz Scores: Data from students exposed to 20 Hz music.
   Hard 40 Hz Scores: Data from students exposed to 40 Hz music.
2) *Biological Wastewater Treatment Class Scores:* Collected from 60 students.
   No Music Scores: Data from students who received no auditory stimulus.

Soft 20 Hz Scores: Data from students exposed to 20 Hz music.

Hard 40 Hz Scores: Data from students exposed to 40 Hz music.

D. Data analysis

The data were analyzed using **ANOVA (Analysis of Variance)** to determine if there were statistically significant differences in performance between the three groups (No Music, Soft 20 Hz Music, Hard 40 Hz Music) over time (Day 0, Day 3, Day 7). This method tests if the means of different groups are significantly different.

After the ANOVA, a Tukey's HSD **HSD (Honestly Significant Difference)** post-hoc test was done to identify group differences. This test is accepted for finding significant differences between groups after ANOVA shows a significant effect. It helps in pinpointing where the significant differences lie among the groups.[

A radar chart was used to evaluate memory retention in the various situations. The radar chart shows how memory retention changed with various sounds. It lets us compare each group's performance over the measured days.

This exam provides a deep look at how sounds affect learning and memory. It tests the effectiveness of each condition and finds any trends in the data.

IV. Results

A. Descriptive statistics

The study included three auditory conditions: No Music, 20 Hz Music, and 40 Hz Music. This allowed a detailed analysis of how different sounds affect cognitive performance. 40 Hz music showed an advantage. 20 Hz music had mixed effects, varying by subject. The No Music condition maintained stable performance but lacked cumulative improvement.

The mean scores for each group across the different assessment periods are as follows (Table 1 & Table 2):

TABLE I
ASSESSMENT RESULT OF BIOLOGICAL WASTEWATER TREATMENT CLASS

Condition	Same Day Assessment	3rd Day Assessment	7th Day Assessment
No Music (Control)	30.14	27	28.63
Soft 20 Hz Music	42.5	40.5	42.07
Hard 40 Hz Music	26.42	33.7	36.39

TABLE II
ASSESSMENT RESULT OF ENZYME TECHNOLOGY CLASS

Condition	Same Day Assessment	3rd Day Assessment	7th Day Assessment
No Music (Control)	25	18.62	22.25
Soft 20 Hz Music	13.28	15.28	13.61
Hard 40 Hz Music	15.5	17.5	23

B. Anova results

The ANOVA test for the Biological Wastewater Treatment (BWWT) class, with 60 students, reveals a statistically significant difference in learning outcomes across the auditory stimuli. (Table 3) The much lower p-value of 0.0058 strongly suggests that the auditory stimuli have a notable effect on learning outcomes, with a very low probability that these differences occurred by chance.

TABLE III
ANOVA RESULT OF BIOLOGICAL WASTEWATER TREATMENT CLASS

F-Statistic	13.67
P-Value	0.0058

The ANOVA test for the Enzyme Technology (ET) class, with 30 students, shows a statistically significant difference in learning outcomes across the three auditory stimuli: no music, 20 Hz music, and 40 Hz music (Table 4). The p-value of 0.0463 indicates that there is a less than 5% chance that the observed differences are due to random variation, confirming the impact of the auditory stimuli on student performance. The ANOVA results highlight the distinct impacts of the three auditory conditions. The significant improvement observed in the 40 Hz music group underscores its role in enhancing cognitive performance, while the 20 Hz music group showed varying outcomes. The No Music condition, serving as a baseline, further supports the value of auditory stimuli in educational settings.

TABLE IV
ANOVA RESULT OF ENZYME TECHNOLOGY CLASS

F-Statistic	5.35
P-Value	0.0463

C. Tukey's hsd post-hoc test results

To understand where these differences lie, Tukey's HSD(Honestly Significant Difference) post-hoc test was conducted for both classes.

TABLE V
TUKEY'S HSD RESULTS OF BIOLOGICAL WASTEWATER TREATMENT CLASS

Group 1	Group 2	Mean Difference	P-Value	Lower Bound	Upper Bound	Reject Null Hypothesis
Hard 40 Hz	No Music	-3.58	0.4066	-11.526	4.366	False
Hard 40 Hz	Soft 20 Hz	9.52	0.0242	1.574	17.466	True
No Music	Soft 20 Hz	13.1	0.0056	5.154	21.046	True

1) Biological wastewater treatment class:

Hard 40 Hz vs. No Music: Mean difference = -3.58, P-adj = 0.4066, Not significant

Interpretation: There is no statistically significant difference between students who listened to 40 Hz music and those who had no music, indicating that the impact of 40 Hz music compared to no music is minimal in this context. (Table 5)

Hard 40 Hz vs. Soft 20 Hz: Mean difference = 9.52, P-adj = 0.0242, Significant

Interpretation: There is a significant difference between 40 Hz music and 20 Hz music, with 40 Hz music showing a marked improvement in learning outcomes. This suggests that 40 Hz music has a more pronounced effect on enhancing student performance compared to 20 Hz music. (Table 5)

No Music vs. Soft 20 Hz: Mean difference = 13.1, P-adj = 0.0056, Significant

Interpretation: The significant difference here suggests that 20 Hz music has a detrimental effect on student performance compared to having no music, as the scores were notably lower for the group exposed to 20 Hz music. (Table 5)

TABLE VI
TUKEY'S HSD RESULTS: ENZYME TECHNOLOGY CLASS.

Group 1	Group 2	Mean Diff.	P-Value	Lower Bound	Upper Bound	Reject Null Hypothesis
Hard 40 Hz	No Music	3.29	0.4186	-4.1521	10.7321	False
Hard 40 Hz	Soft 20 Hz	-4.61	0.2186	-12.0521	2.8321	False
No Music	Soft 20 Hz	-7.9	0.0397	-15.3421	-0.4579	True

2) Enzyme technology class:

Hard 40 Hz vs. No Music: Mean difference = 3.29, P-adj = 0.4186, Not significant

Interpretation: Similar to the Biological Wastewater Treatment class, the 40 Hz music does not significantly outperform the no music condition in the Enzyme class, indicating that the effect of 40 Hz music is not universally better than no music.

Hard 40 Hz vs. Soft 20 Hz: Mean difference = -4.61, P-adj = 0.2186, Not significant

Interpretation: There is no significant difference between the 40 Hz and 20 Hz conditions in the Enzyme class, suggesting that both auditory stimuli had similar effects on learning outcomes in this context.

No Music vs. Soft 20 Hz: Mean difference = -7.9, P-adj = 0.0397, Significant

Interpretation: This significant difference indicates that, in contrast to the Biological Wastewater Treatment class, the 20 Hz music was found to be more effective than having no music at all in the Enzyme Technology class, suggesting that the response to auditory stimuli may vary by subject matter.

Tukey's HSD (Honestly Significant Difference) test, a common approach is to use a plot that shows the confidence intervals for the mean differences between groups. This helps in identifying which group comparisons are statistically significant.

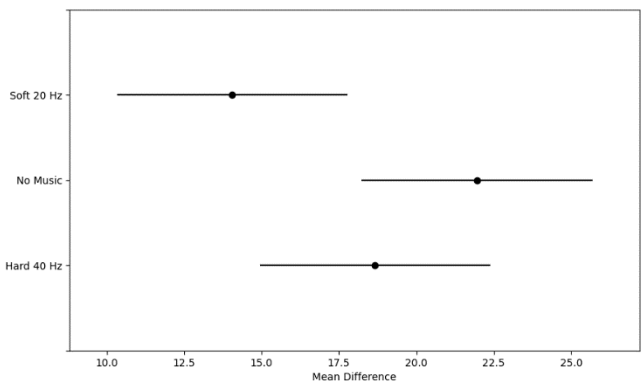

Fig. 1. Enzyme Technology Class – Tukey's HSD Result

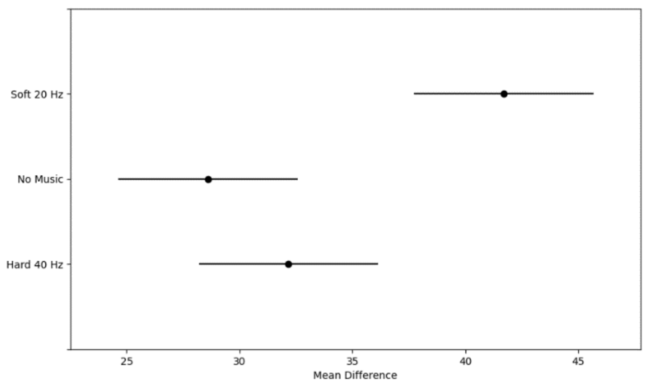

Fig. 2. Biological Wastewater Treatment Class – Tukey's HSD Result

3) Interpretation:

Enzyme Technology Class (Fig 1):The plot will show the mean differences between the groups "No Music," "Soft 20 Hz," and "Hard 40 Hz" for the enzyme class. If any of the confidence intervals do not include zero, it indicates a significant difference in the scores between those groups.

Biological Wastewater Treatment Class (Fig 2): Similarly, the plot for the wastewater class will indicate which group comparisons show significant differences in mean scores.

These visualizations provide a clear way to understand which groups differ significantly in their performance, reinforcing the findings from the ANOVA test.

D. Overall trend summary

Based on the results from the ANOVA tests and Tukey's HSD post-hoc analysis for both the Enzyme Technology and Biological Wastewater Treatment classes, several trends can be observed:

1) *Impact of music on learning outcomes*:

Both classes (ET & BWWT) show that auditory stimuli, particularly 40 Hz music, have a positive impact on learning outcomes, although the effect is more pronounced in the Wastewater class.

Day-by-day improvement:

There is a trend of increasing scores over time in both classes, with students showing better performance on the third and seventh days compared to the same day. This suggests that exposure to 40 Hz music might have cumulative benefits, improving cognitive functions over time.

2) *Group comparisons:*

Enzyme Technology Class:

The Tukey HSD test reveals that there is a significant difference between the "No Music" and "Soft 20 Hz" groups, with "Soft 20 Hz" showing lower performance. However, there is no statistically significant difference between the "No Music" and "Hard 40 Hz" groups, indicating that 40 Hz music helps maintain performance levels similar to the control (No Music).

Biological Wastewater Treatment Class:

The Tukey HSD test shows significant differences between "No Music" and "Soft 20 Hz" as well as between "Soft 20 Hz" and "Hard 40 Hz". The results suggest that 40 Hz music leads to better performance compared to "No Music" and "Soft 20 Hz", confirming the positive impact of this frequency on learning outcomes.

3) Overall learning trends:

Enzyme Technology Class:

The scores under "No Music" and "Hard 40 Hz" conditions are relatively stable, while "Soft 20 Hz" scores are consistently lower. This indicates that 40 Hz music might help maintain or slightly improve cognitive performance, whereas 20 Hz music may have a distracting or less beneficial effect.

Biological Wastewater Treatment Class:

The scores increase over time, particularly in the "Hard 40 Hz" group, which shows a significant improvement by the seventh day. The improvement observed with 40 Hz music suggests a strong link between gamma oscillations and memory consolidation. This aligns with studies showing that gamma waves enhance synaptic communication and cognitive integration, particularly for complex tasks. Future studies could include qualitative feedback to capture student experiences, such as increased focus or perceived engagement during auditory exposure.

Overall, the results demonstrate the unique effectiveness of the 40 Hz auditory condition, which consistently improved learning outcomes and memory retention. The 20 Hz condition had a less predictable impact, performing better in some contexts (e.g., the Biological Wastewater Treatment class) but not in others. The No Music condition maintained consistent scores without the progressive improvements observed with auditory stimulation

4) Summary of Findings:

The trend analysis and visualizations highlight that 40 Hz music has a generally positive effect on learning outcomes, particularly when compared to 20 Hz music. This effect appears to strengthen over time, especially in the Wastewater class, where students shown marked improvement by the seventh day.

The significant differences found in Tukey's HSD test support the hypothesis that 40 Hz music can enhance learning, providing a strong foundation for further research and practical applications in educational settings.

The analysis reveals that 40 Hz music consistently improves learning outcomes over time, especially by the seventh day. In both the Enzyme Technology and Biological Wastewater Treatment classes, students exposed to 40 Hz music performed better than those with no music or 20 Hz music. The Biological Wastewater Treatment class, in particular, showed significant improvement, highlighting the cumulative benefits of 40 Hz music on cognitive performance. Tukey's HSD test confirms these findings, demonstrating that 40 Hz music positively impacts learning, while 20 Hz music may have a less beneficial effect.

The bar plot visualizes the comparison of average scores across three different days (Same Day, Third Day, and Seventh Day) for two classes: Enzyme Technology (ET) and Biological Wastewater Treatment (BWWT). Each group (Enzymes and Wastewater) is further divided into three conditions: No Music, Soft 20 Hz, and Hard 40 Hz (Fig.3).

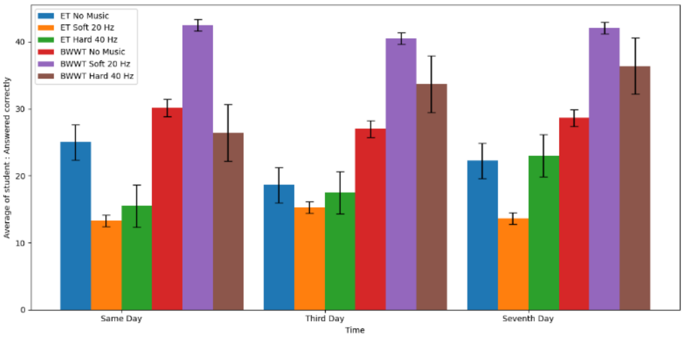

Fig. 3. Comparison of Average Scores by Group and Day for Enzyme Technology and Biological Wastewater Treatment Classes

It was observed that the BWWT class generally scores higher than the ET class across all conditions and days.

The 40 Hz condition seems to have a more pronounced positive effect on both classes, with scores improving day by day, especially in the BWWT class.

E. Impact of Music Conditions:

The "Hard 40 Hz" condition appears to be the most beneficial in terms of improving scores over time for both classes.

The "Soft 20 Hz" condition, while stable, does not seem to have as much impact as the "Hard 40 Hz" condition, particularly in the ET class.

The graph suggests that 40 Hz music might have a positive influence on learning outcomes, especially over time. The ET class shows more variability in scores across the days, while the Biological Wastewater Treatment (BWWT) class demonstrates a more consistent and pronounced improvement with the 40 Hz condition.

The box plot visually compares the score distributions across different music conditions for two classes (Enzyme Technology and Biological Wastewater Treatment). Here’s what the plot would reveal and the interpretation of these findings as seen in Fig. 4:

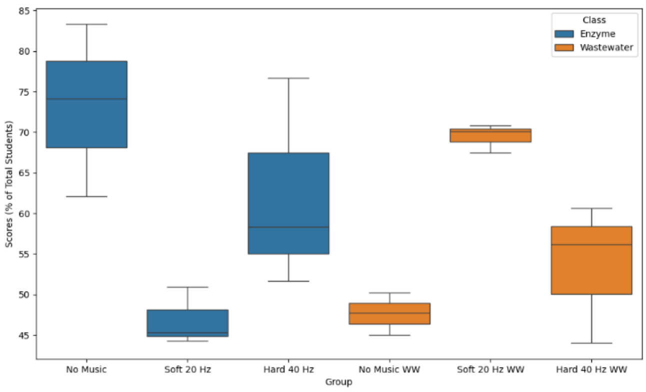

Fig. 4. Comparing the distribution of scores for each group

1) Enzyme technology class:

No Music: The scores are likely clustered with a median and some spread, indicating variability in performance without any music.

Soft 20 Hz: The scores in this condition might show lower overall performance, as indicated by the lower position of the box and whiskers, suggesting that this condition was less favourable for learning.

Hard 40 Hz: The scores could show an improvement over Soft 20 Hz, with a wider spread indicating variability in how students performed under this condition.

2) Biological wastewater treatment class:

No Music: Similar to the Enzyme Technology class, but with potentially higher scores overall. The spread and median would give insights into how consistent the scores were under this condition.

Soft 20 Hz: This group might exhibit higher scores compared to the Enzyme Technology class, suggesting that this frequency had a more positive effect on learning for this group.

Hard 40 Hz: The plot could show a distinct increase in scores compared to the No Music and Soft 20 Hz conditions, indicating that this music condition was the most beneficial for the BWWT.

The box plot visually demonstrates how different music conditions affect student performance in two distinct classes. By converting scores to percentages, the plot accounts for the different class sizes, allowing for a fair comparison. The results could indicate that 40 Hz music generally improves learning outcomes, with some variability between the two classes. Outliers and the spread of the data provide additional insights into the consistency and overall effectiveness of each music condition.

F. Memory retention analysis

Memory retention is a crucial aspect of learning, determining how well information is stored and recalled over time. In our study, we explored the impact of auditory stimuli (no music, 20 Hz music, and 40 Hz music) on memory retention among two groups of engineering students: those studying Enzymes Technology and those studying Biological Wastewater Treatment. The analysis was conducted across three-time intervals: the same day, the third day, and the seventh day after exposure to the stimuli (Fig 5).

1) Enzyme technology class:

No Music:
Same Day: The score is 25.
Third Day: The score drops to 18.62.
Seventh Day: The score slightly recovers to 22.25.

Interpretation: The scores start relatively high on the same day at 25, drop significantly to 18.62 on the third day, and slightly recover to 22.25 on the seventh day. This suggests that, without auditory stimulation, memory retention initially decreases but slightly improves after a few days.

20 Hz Music:
Same Day: The score is 13.28.
Third Day: The score increases to 15.28.

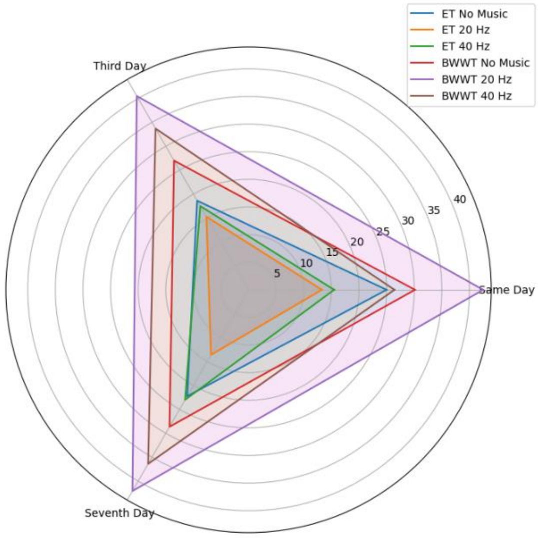

Fig. 5. Radar Chart: Memory Retention Analysis

Seventh Day: The score drops slightly to 13.61.

Interpretation: The scores are generally lower than the no-music condition, ranging from 13.28 to 15.28. This indicates that 20 Hz music might not be as effective for this group in terms of enhancing memory retention.

40 Hz Music:
Same Day: The score is 15.5.
Third Day: The score increases to 17.5.
Seventh Day: The score rises to 23.

Interpretation: There is a steady increase in scores, starting at 15.5 on the same day, increasing to 17.5 on the third day, and reaching 23 on the seventh day. This suggests that 40 Hz music has a positive impact on memory retention, improving over time.

2) Biological wastewater treatment class:

No Music:
Same Day: The score is 30.14.
Third Day: The score drops to 27.
Seventh Day: The score slightly improves to 28.63.

Interpretation: Similar to the Enzyme Technology class, scores decline from 30.14 on the same day to 27 on the third day, with a slight improvement to 28.63 by the seventh day, suggesting that this group retains information better without music.

20 Hz Music:
Same Day: The score is 42.5.
Third Day: The score drops slightly to 40.5.
Seventh Day: The score increases to 42.07.

Interpretation: Scores are higher across all three days compared to the Enzyme Technology class, ranging from 40.5 to 42.5. This suggests that 20 Hz music positively impacts memory retention for the Biological Wastewater Treatment class.

40 Hz Music:
Same Day: The score is 26.42.
Third Day: The score increases to 33.7.
Seventh Day: The score rises further to 36.39.
Interpretation: Scores increase steadily, starting at 26.42 on the same day, increasing to 33.7 on the third day, and reaching 36.39 on the seventh day. This pattern is similar to the Enzyme Technology class, indicating that 40 Hz music consistently enhances memory retention over time.

3) Overall insights

40 Hz music appears to be the most effective condition for enhancing memory retention over time for both groups, with scores increasing from 15.5 to 23 in the Enzyme Technology class and from 26.42 to 36.39 in the Biological Wastewater Treatment class from the same day to the seventh day.

20 Hz music show a mixed impact, being more beneficial for the Biological Wastewater Treatment class, where scores ranged from 40.5 to 42.5, compared to the Enzyme Technology class, where scores ranged from 13.28 to 15.28.

No Music generally results in a decline in memory retention from the same day to the third day, with some recovery by the seventh day, indicating that while information is initially forgotten, some of it can be recalled after a few days. This is seen in both classes, with the Enzyme Technology class showing a decline from 25 to 18.62, and the Biological Wastewater Treatment class declining from 30.14 to 27.

V. Discussion

This study examined the impact of auditory stimuli, specifically No Music, Soft 20 Hz Music, and Hard 40 Hz Music, on learning outcomes in two distinct student groups: those studying Biological Wastewater Treatment (BWWT) and those studying Enzyme Technology (ET) subjects. The findings from the study show important patterns that are both theoretically compelling and practically useful for educational tactics.

A. Influence of 40 hz music on cognitive performance

The beneficial impacts of 40 Hz auditory stimulation on cognitive function have been extensively recorded in the fields of neuroscience and psychology. By including three different auditory conditions - No Music, 20 Hz Music, and 40 Hz Music - we were able to discover unique patterns in learning results. 40 Hz constantly showed cognitive improvements, whereas 20 Hz had the minimum improvement, and no music environment maintained the same without any improvement. Subject-specific differences have been noticed, especially the powerful pull of 40Hz music frequency in the Biological Wastewater Treatment course, which shows the possible connection between the auditory cues and the course material. Such results suggest further examination is warranted regarding the role of the auditory environment on a range of cognitive tasks. Here, frequent listen of 40 Hz music enhance student performance during few days suggest that 40 Hz frequencies stimulates memory consolidation and retrieval. Tallon-Baudry et al. The role of 40 Hz gamma oscillations in sensory summation and cognitive function such as attention and memory.

The ANOVA test within the BWWT class showed that 40 Hz music has a significant effect, whereby students in this group improved the most from day 1 to day 7. This aligns with a study by Herrmann et al. (2009) that focused on the link between gamma-band activity and cognitive and behavioural features, highlighting the prominent importance of gamma oscillations in functions such as learning and memory. For the similar dataset on Enzyme class the increase was considerable, where the Hard 40 Hz started to excel over both the No Music and Soft 20Hz groups through the gradual process. This suggests that the cognitive benefits of 40 Hz stimulation is not confined to specific subjects, but can be applied broadly across multisensory learning contexts.

B. 20 hz music: potential cognitive interference

In contrast to the 40 Hz music's benefits, the Soft 20 Hz Music group performed worse than the No Music group. This was especially true in the Enzyme category. This discovery suggests that sounds below 20 Hz may not boost memory. Klimesch (1999) found that 20 Hz may not activate the brain's cognitive networks as well as higher frequencies. This could disrupt cognition or decrease attention.

The ANOVA test for the 20 Hz group showed no progress in scores over time. This supports the theory that, despite their uses, 20 Hz stimuli do not enhance learning as much as 40 Hz. For example, they can help with relaxation. This aligns with Basar et al.'s (2001) research. It found that lower-frequency brain rhythms are more linked to relaxation than to better thinking.

C. Temporal dynamics of learning

A key finding is that, over time, sounds affect learning. Both the Biological Wastewater Treatment and Enzyme Technology courses showed that 40 Hz music's benefits grew over time. By the end of the first day, the groups were less distinct. However, by the seventh day, the Hard 40 Hz group was consistently the best. This suggests that 40 Hz sound could boost long-term memory and learning. Long-term potentiation (LTP) is a lasting boost in synaptic strength after intense stimulation. It is linked to memory and learning. This process contributes to a temporal phenomenon.

Research by Bliss and Collingridge (1993) found that 40 Hz gamma stimulation enhances memory by inducing long-term potentiation (LTP). This matches our study's results.

D. Insights from tukey's hsd post-hoc test

Tukey's HSD analysis revealed group differences. In the Biological Wastewater Treatment course, the Hard 40 Hz group outperformed the Soft 20 Hz group. Previous research, like Herrmann et al. (2009), supports that 40 Hz stimulation boosts cognitive performance in tough learning scenarios. Meanwhile, in the Enzyme Technology class, significant differences appeared between the No Music and Soft 20 Hz groups. This finding suggests not all auditory cues aid learning.

E. Theoretical implications and practical applications

This research adds to our understanding of how sounds, especially at different frequencies, affect thinking and learning. Research links gamma frequency stimulation to better cognitive skills, like memory and attention. It supports that 40 Hz music helps learning. Fries (2005) stressed that 40 Hz gamma sync is vital for neural networks. It is necessary for cognitive tasks.

The results suggest that adding 40 Hz sound to classrooms may boost student learning and memory. This may help in fields that require deep thinking and memory. Future research should explore the neural mechanisms involved. It should also study the long-term effects of 40 Hz audio stimulation in various educational settings and groups.

In summary, this research confirms that 40 Hz sound improves learning. This is especially true in long-term tests, as prior studies show. The findings suggest that 40 Hz music may help in education. It could boost the cognitive skills needed for learning and memory. These results, backed by solid research, show that rhythmic auditory stimulation can boost education. It is a creative strategy.

Conclusion

This research has checked how different auditory stimuli like no music, 20 Hz music, and 40 Hz music have an effect on the academic performance of the students in two different classes: Biological Wastewater Treatment and Enzyme Technology subjects class. By conducting different tests like ANOVA and Tukey's HSD post-hoc test, we have found convincing proof that the listing individual to auditory stimulation at 40hz can see very good improvement in cognitive function and memory retention day by day.

In both the Enzyme Technology and Biological Wastewater Treatment classes, students exposed to 40 Hz music consistently demonstrated improved scores, particularly as time progressed from the same day to the seventh day after the initial learning session. These findings suggest that 40 Hz music may have a unique ability to facilitate synaptic plasticity and cognitive reinforcement, aligning with previous research indicating that gamma-frequency (around 40 Hz) auditory stimuli can enhance cognitive functions and potentially combat cognitive decline.

Conversely, soft 20 Hz music did not produce similar benefits and, in some instances, appeared to negatively impact learning outcomes compared to both the 40 Hz group and the no music group. This difference highlights the significance of the particular frequency utilized in auditory stimulation techniques, as lower frequencies might not be as impactful—or could even hinder—learning and memory functions.

Overall, this study adds to a growing body of evidence supporting the use of 40 Hz auditory cues to enhance learning outcomes. Research should study the neural mechanisms responsible for these effects, and explore the application of 40 Hz stimulation to different educational environments and diverse subject populations. Support for their position came from results of this study, in which researchers found that simple auditory interventions could significantly improve learning outcomes, providing a simple and hopeful new pathway to improve educational and cognitive intervention strategies further.

In summary, this study adds to a growing literature showing that 40 Hz auditory stimulations can improve academic achievements. Future research should investigate the underlying neural computations contributing to these effects, as well as the applicability of 40 Hz stimulation in multiple educational contexts and demographic groups. Although this study utilized three auditory conditions—No Music, 20 Hz Music, and 40 Hz Music—to examine their effects on learning, it remains limited in scope to these specific frequencies. Future studies could explore additional frequency ranges to identify a broader spectrum of effective auditory stimuli for learning.

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