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Enhancing Preservice Science Teachers' Conceptual Understanding of Properties of Waves Through Mnemonics: *A Classroom Intervention Study*

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Abstract

This quantitative classroom intervention study investigates the effectiveness of using mnemonics to enhance conceptual understanding of the topic of proprieties of waves in physics among preservice teachers. The sample comprises 30 final year Natural Science & Health Education undergraduate students at a university in Namibia. The research aims to assess the impact of a targeted mnemonic intervention in grasping physics concepts. Participants' initial conceptual understanding of the concepts in the topic of proprieties of waves in physics is evaluated through pre-intervention assessments. Subsequently, a carefully designed mnemonic-based instructional intervention is implemented over a defined period. Post-intervention assessments measure the effectiveness of the intervention, comparing the participants' conceptual understanding before and after the mnemonic-based teaching. Potential findings revealed significant improvements in the participants' conceptual understanding of the concepts in the topic of properties of waves following the intervention. The study also explores the participants' feedback on the use of mnemonics, providing insights into their perceptions of its effectiveness as a pedagogical tool. This research contributes to the broader field of science education by offering evidence-based strategies to enhance the preparation of preservice teachers, particularly in the challenging domain of physics, ultimately fostering more effective and engaging teaching practices in the future.

Keywords: *Preservice teachers, Conceptual understanding, Physics, Mnemonics, Classroom intervention*

INTRODUCTION

Most teacher-training institutions across the globe emphasise the construct of active learning (Moreira et al., 2021; Rodrigues, 2020; Rodríguez-Sabiote et al., 2020; Røe et al., 2022) particularly for undergraduate students trained in the fields of science, technology, engineering, and mathematics (STEM). Active learning is acknowledged as an effective teaching pedagogy by many scholars, as it provides students with equitable learning outcomes (Howell, 2021; Lombardi et al., 2021; Theobald et al., 2020). The pedagogical landscape of contemporary science education is shaped by various factors that hinder students' understanding of scientific concepts, with a particular emphasis on the domain of physics (Sommeillier et al., 2021; Stinken-Rösner et al., 2020). Significantly, among these factors are challenges associated with their effective conceptualisation of scientific principles. These factors may encompass challenges associated with inadequate opportunities for hands-on experimentation, limitations of interactive learning experiences, and a lack of real-world applications within the instructional framework of physics (Jesionkowska et al., 2020; Qureshi et al., 2023; Smith & Gillespie, 2023). According to Rouse (2019), conceptual understanding in physics education is foundational to students' ability to apply principles, solve problems, and engage meaningfully with the subject.

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An in-depth conception of fundamental concepts, such as those related to general wave properties, is vital for students pursuing careers in science education. The study of waves, specifically longitudinal and transverse waves in physics, is essential for comprehending various natural phenomena, from sound propagation to electromagnetic radiation. Moreover, according to Olaniyan (2022), a student's grasp of mechanical waves is essential, forming a foundation for comprehending topics such as physical optics, quantum mechanics, electromagnetic radiation, and other subjects to be presented in the ensuing years. However, many research study have shown that undergraduate students often grapple with distinguishing between these wave types in terms of their descriptions, production, propagation (wave travel) and representations on diagrams and/or wave forms, highlighting the need for effective pedagogical strategies to enhance their conceptual understanding (Lass & Donai, 2021).

Mnemonics are often used in teaching science concepts to enforce active learning and conceptual understanding of science concepts. The word mnemonic has its original roots from the Greek word 'mnemonikos', signifying something "of or related to memory" and it is classified as a technique designed to enhance memory (Cheriti et al., 2023; Nakamura, 2022). Moreover, Cheriti et al. (2023), outlined that the term "mnemonics generally refer to any device that can frequently improve the way that knowledge is sorted or learned and afterward remembered" (p. 8). Mnemonics play a pivotal role in facilitating conceptual learning by providing memory aids and organising information in a memorable way (Al-Maqbali et al., 2022; Cheriti et al., 2023; Nakamura, 2022). Furthermore, Al-Maqbali et al. (2022), outlined that mnemonics are recognised as tools or devices that help to assist students in recalling information by generating mental cues designed to retrieve the desired information. Moreover, a mnemonic is a strategy wherein information slated for retention is encountered along a predefined route through imagined locations, establishing robust spatial and visual associations between the content and distinct settings and vivid images. (Drigas et al., 2022).

Researchers have identified three essential principles for successful mnemonics to involve the utilisation of structure, reinforcement to establish distinctive memories, and prompts to facilitate information retrieval (Nakamura, 2022). To this end, a consensus among the majority of researchers and scholars regarding the use of mnemonics in teaching science, is that mnemonics encompass any device, technique, or strategy primarily employed to convert difficult-to-retain information into something that is memorable and easily retrievable, consequently improving memory performance (Akpan et al., 2021; Cheriti et al., 2023; Ni & Hassan, 2019). Mnemonics come in many types such as: loci method, keyword method, first-letter mneumonic, rhyme, peg-word mnemonic, spatial grouping, the finger method etc., (Cheriti et al., 2023). The mnemonics used in this paper are first-letter mnemonics.

Properties of waves, including the characteristics of waves such as amplitude, frequency, and wavelength, are central constructs to understanding diverse physical phenomena which are concepts that are taught to final year students in Natural Science & Health Education (NSHE) at the university at which this study was conducted. For instance, the ability to differentiate between longitudinal and transverse waves is crucial for comprehending how energy is transmitted in various mediums. A solid grasp of wave properties is also indispensable in fields like acoustics, where understanding the relationship between amplitude and frequency is vital in explaining the perception of sound loudness and pitch (Lass & Donai, 2021; Whiting et al., 2022).

Research Objectives

Given the challenges associated with teaching and learning abstract concepts in physics—particularly wave phenomena—this study aims to explore how mnemonic-based instructional strategies can enhance understanding among preservice teachers. The research is grounded in the premise that effective memory aids and structured learning interventions can bridge gaps in conceptual clarity, foster active engagement, and ultimately improve academic performance. In light of this, the specific objectives of the study are:

1. To investigate the effectiveness of mnemonic instructional strategies in improving preservice teachers' conceptual understanding of wave properties.
2. To assess the role of structured memory aids (such as TIL and LaPf) in facilitating the retention and application of key wave concepts.
3. To evaluate preservice teachers' perceptions of mnemonic-based teaching methods and their impact on classroom engagement and learning confidence.

THEORETICAL FOUNDATIONS

The Role of Mnemonics in Facilitating Learning

Mnemonics, as memory aids or learning tools, can play a pivotal role in enhancing students' conceptual understanding of scientific phenomena (Al-Maqbali et al., 2022; Cioca & Nerișanu, 2020). To ease students' understanding, Figure 1., which shows the diagrammatic difference between transverse and longitudinal waves from which the researcher developed the TIL and LaPf mnemonics has been presented hereunder.

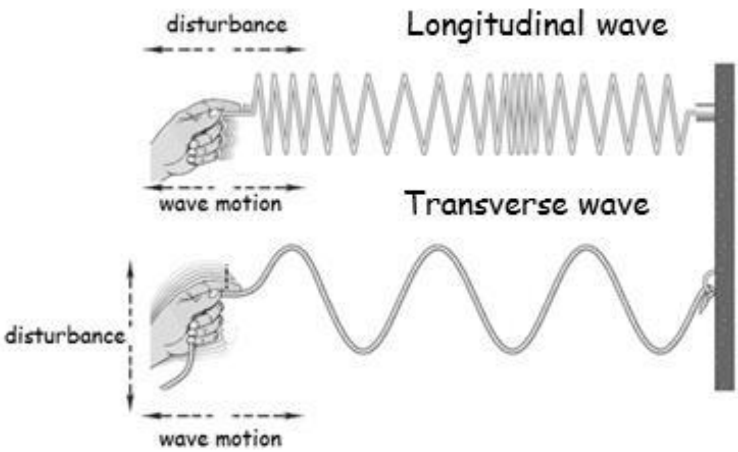

Figure 1. The diagrammatic difference between Transverse and Longitudinal waves

In this study, the researcher introduces the "TIL" and "LaPf" concepts as mnemonics to help students remember and conceptualise the general properties of waves in physics. Particularly, the TIL concept used as mnemonic as depicted in Figure. 2, will be used by students to be able to distinguish between longitudinal and transverse waves, despite the students' difficulties in distinguishing the two concepts. In addition, the current research study addresses this challenge by introducing the TIL concept as mnemonic which aims to facilitate an understanding of the differences between the two wave types, providing students with a structured approach to conceptualising and remembering key distinctions.

The differences offered by the TIL concepts lies in the way, transverse and longitudinal waves are produced, propagated and distinguished in terms of how the wave propagation (wave travel) and disturbance either form perpendicular or parallel lines. Thus, the "TIL" mnemonic relates transverse to longitudinal waves in terms of how they are produced and propagated. In terms of transverse waves, the disturbance is always perpendicular to the propagation and/or the direction in which the wave travels (Argudo & Oh, 2022; Bennett, 2022), thus the "T" part of the TIL shows how perpendicular lines on the head of a T and on the tail of a T are denoted (see Figure 2). Moving on to the longitudinal waves, the "IL" part of the TIL shows the two parallel lines, because in longitudinal waves, the disturbance and the propagation are parallel (Barile et al., 2023; Xi et al., 2022) to each other (see Figure 2).

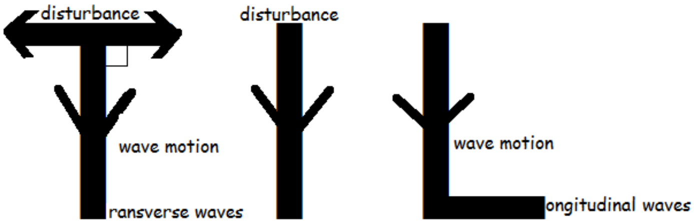

Figure 2. The TIL Concept (Source: Researcher, 2023)

In terms of the LaPf mnemonic which relates how the properties of sound waves (loudness and pitch) are influenced by amplitude and frequency (Devkota, 2019), the researcher will demonstrate how his mnemonic strategy not only aids in memorisation but also fosters a deeper understanding of the relationships between wave properties. Figure 3., represents the researcher's developed LaPf mnemonic. Through the LaPf mnemonic, it is believed that students will be able to remember the properties of waves responsible for the changes in the properties of sound in terms of its loudness and pitch (Devkota, 2019).

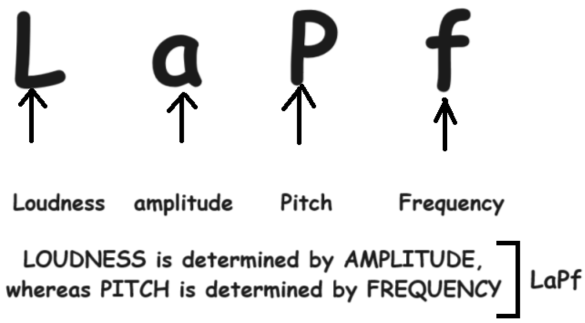

Figure 3. The LaPf Concept (Source: Researcher, 2023)

Students often encounter challenges when distinguishing between the two fundamental properties of waves that significantly influence the quality of sound such as the loudness and pitch, particularly when examining waveforms (Iliaki et al., 2019). As outlined earlier, loudness corresponds to the amplitude of a wave, representing the magnitude or intensity of the sound (Rumsey, 2021). On the other hand, pitch is associated with the frequency of the wave, indicating how high or low the sound is perceived (Gockel et al., 2020; Hirst & de Looze, 2021).

When students are encountered with waveforms to distinguish how the pitchiness of a sound note relates to its loudness, the challenge arises because changes in amplitude and frequency can manifest differently in waveforms, sometimes leading to confusion (Amin et al., 2023; Mari-Acevedo et al., 2019). For instance, a visually intense waveform might be mistakenly associated with higher pitch instead of increased loudness (Braun et al., 2020; Soland, 2022). The particulars of waveforms and the intriguing correspondence between amplitude and frequency require students to develop a keen understanding of wave properties and the corresponding perceptual aspects of sound (Lass & Donai, 2021; Steiglitz, 2020). This challenge emphasizes the importance of either hands-on, interactive learning experiences and/or the use of mnemonics that allow students to visualize, manipulate and remember (Akhter et al., 2021; Cioca & Nerișanu, 2020; Liao et al., 2019) waveforms depicting high/low pitch as well as loud/soft sounds respectively, fostering a deeper understanding of the complex connection between wave characteristics and the perceived qualities of sound. Waveforms depicted in Figures 4 and 5 are used to indicate how the LaPf mnemonic may be useful in helping students to understand and remember how pitch and loudness of a sound note relates to the frequency and amplitude respectively.

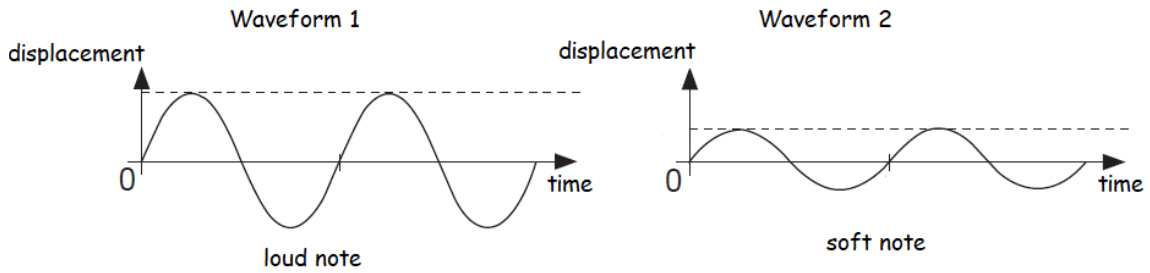

Figure 4. Two waveforms showing how the loudness of a sound note compares

For example, as it can be seen in Figure 4., waveforms 1 and 2 display objects producing sound notes with the same pitch (as their frequency is the same, they all have two complete waves/oscillations/vibrations and/or cycles and hence have a frequency of 2 Hz, provided that the waves were produced in one second), however their loudness is different. Waveform 1 is louder than waveform 2, (it has a greater amplitude than waveform 2).

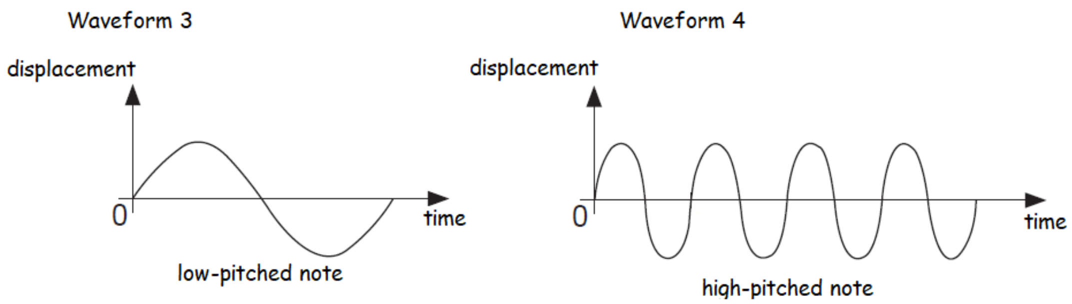

Figure 5. Two waveforms showing how the pitch of a sound note compares

Waveforms 3 and 4 have the same loudness (as their amplitude is the same). Waveform 3 has a low-pitched note than waveform 4 (as its frequency is lower than that of waveform 4: in waveform 3 there is only once complete wave/oscillation/vibration and/or cycle, whereas in waveform 4, there are for complete waves/oscillations/vibrations and/or cycles) provided, all these waves were produced in one second.

Apart from the TIL and the LaPf mnemonics, an already developed 'Isaac Newton's colour sequence' (red, orange, yellow, green, blue, indigo, violet) – ROYGBIV mnemonic (Webster, 1966) which helps students to remember the order of colours in the visible light spectrum (the colours of the rainbow) in terms of the differences between their frequency and wavelength will also be incorporated to strengthen the scope of mnemonics usage in physics. By incorporating mnemonic strategies, this study aims to enhance preservice teachers' conceptual understanding of properties of waves, paving the way for more effective teaching and learning experiences in physics education for preservice teachers.

Physics education in Namibian science classrooms has seen significant strides, exacerbated by the lack of proper training of teachers by means of the incorporation of different teaching strategies (Akuma & Callaghan, 2019; Fitzgerald et al., 2019). However, there remains a noticeable gap in the literature when it comes to the conceptual understanding of general wave properties. While existing studies may have dwelled upon certain aspects of wave theory (Cheriti et al., 2023; Nakamura, 2022), there is a lack of comprehensive research specifically addressing the challenges faced by preservice teachers in understanding the particulars of wave properties. The current study aims to bridge this gap by probing unique challenges faced by preservice teachers in Namibian classrooms when teaching and learning about properties of wave. By focusing on the conceptual understanding of these fundamental principles, the research seeks to contribute valuable insights that can inform improvements in physics education methodologies, particularly at teacher training institutions in Namibia.

Furthermore, within the broader context of science education, the use of mnemonics as a teaching tool is an area that requires more attention in the Namibian context. Mnemonics, which involve memory aids or devices, have been proven effective in various educational settings (Farrokh et al., 2021; Johnson et al., 2020; Jones et al., 2021). However, their application and impact on enhancing conceptual understanding in physics, especially in the Namibian context, have not been extensively explored. The current study also aims to fill this gap by investigating the usefulness of mnemonics as a pedagogical approach to improve preservice teachers' conceptual understanding of properties of waves. By combining the specific focus on wave properties with the innovative use of mnemonics, the study seeks to provide a holistic framework for advancing science education practices in Namibian classrooms.

For preservice science education teachers, mnemonics can serve as effective instructional strategies as presented under the following headings.

Aiding Memory Retrieval

According to Tullis and Qiu (2022), mnemonics provide students with memory prompts that help them recall complex physics concepts more easily. Mnemonics play a crucial role in aiding memory retrieval by providing learners with effective strategies to recall information (Akpan et al., 2021; Hartman & Nelson, 2021). One widely recognized mnemonic technique is the use of acronyms, where the initial letters of a set of items are arranged to form a memorable word or phrase (Auliya, 2023; Kurniarahman, 2023; Radović & Manzey, 2019). As there exist a number of mnemonic representations, the focus of this study was on the first-letter mnemonics as outlined earlier. For instance, in the field of biology, the acronym "DNA" serves as a mnemonic for the complex term "deoxyribonucleic acid" (Weinberger & Merhav, 2022). In chemistry for example, the mnemonic "LEOGER" helps students to recall the processes of oxidation and reduction. "LEOGER" denotes that "loss of electrons is oxidation, gain of electrons is reduction" (Casparian & Sirokman, 2016). Lastly in physic, the already presented "ROYGBIV" mnemonic represents the colours of the visible light spectrum such as Red, Orange, Yellow, Green, Blue, Indigo, Violet (Branaghan et al., 2021; Nakamura, 2022; Newton, 2022). This association helps learners quickly retrieve the relevant information during exams or discussions. Similar to Kılıç and Yolbulan Okan (2021), the method of creating vivid mental images or associations through the use of rhymes and alliteration enhances memory retrieval. The rhythmic and repetitive nature of mnemonics thus assists in reinforcing connections between information and facilitates easier recall, contributing to a more efficient learning process (Tomczak & Lew, 2019; Williams, 2022).

Memory retrieval is a crucial aspect of the cognitive processes underlying learning and information retention (Baddeley, 2020; Cowan et al., 2020). Mnemonics, a set of memory aids or techniques designed to facilitate the recall of information, have been widely studied and applied in various educational and cognitive contexts (Farrokh et al., 2021; Jones et al., 2021; Siagian et al., 2023). These mnemonic devices influence the inherent structure of information to create associations that make it easier for individuals to retrieve stored knowledge. The effectiveness of mnemonics in aiding memory retrieval has been a subject of extensive research, with numerous studies demonstrating their utility across diverse domains (Jones et al., 2021; Roheger et al., 2020; Tullis & Qiu, 2022). One of the key advantages of mnemonics in aiding memory retrieval is their ability to enhance encoding and consolidation processes (Cowan et al., 2021; Greve et al., 2019; Wanner et al., 2020). By associating new information with familiar concepts or creating glowing mental images, individuals can create robust memory traces that are more easily retrievable. This encoding specificity, where the cues used during learning are matched during retrieval, enhances the likelihood of successful recall (Cowan et al., 2021; Cowan et al., 2020). Mnemonics, therefore, serve as cognitive scaffolds that support the construction of a more organized and interconnected mental representation of information, facilitating efficient retrieval.

Furthermore, mnemonics cater to the human brain's inclination towards pattern recognition and associative thinking. The method of loci, for instance, involves associating pieces of information with specific locations in a familiar environment (Caplan et al., 2019). This spatial organization taps into the brain's spatial memory systems, providing a structured framework for retrieving information (Berki, 2019; Diaz-Orueta et al., 2022). Similarly, the phonetic and semantic associations employed in mnemonic techniques exploit the brain's natural inclinations, making it easier to recall information by leveraging pre-existing cognitive pathways (Sperber, 2019).

The versatility of mnemonics is evident in their application across diverse learning environments. From aiding students in memorizing complex sequences of information to supporting individuals with cognitive impairments (Bravou & Drigas, 2019), mnemonics have proven to be adaptable tools for memory enhancement (Baddeley, 2020; Elsisi, 2023). Educational curricula often incorporate mnemonic strategies to assist students in remembering facts, vocabulary, and procedural information. Additionally, healthcare professionals use mnemonic devices to improve patient care by facilitating the recall of critical medical information, showcasing the broad applicability of these techniques.

To this end, the literature overwhelmingly supports the use of mnemonics in aiding memory retrieval (Elsisi, 2023; Jones et al., 2021; Nakamura, 2022; Williams, 2022). Whether applied in educational settings or everyday life, mnemonics offer a powerful and accessible means to enhance memory performance. The cognitive processes underlying memory retrieval benefit from the structured and associative nature of mnemonic techniques, making them valuable tools for individuals seeking to optimize their learning and information retention abilities. As research in this field continues to evolve, further insights into the varied mechanisms through which mnemonics operate will likely contribute to the refinement and expansion of their applications.

Facilitating Understanding and Promoting Retention

Many scholars agree that mnemonics, as cognitive tools, have been employed for centuries to enhance memory and facilitate understanding across various domains (Anderson, 2019; Bein et al., 2021; Çolak & Aydın, 2022; Drushlyak et al., 2021; Papanastasiou et al., 2019; Szőllősi & Racsmány, 2020). The utilization of mnemonic devices has proven to be particularly effective in educational settings, where the goal is often not only to memorize information but also to comprehend and apply it. By optimising the power of association and visualization, mnemonics serve as aids in organizing and retaining complex information, ultimately paving the way for a deeper understanding of the subject matter. One key aspect of how mnemonics facilitate understanding is through the creation of meaningful connections (Hill, 2022; Ni & Hassan, 2019; Radović & Manzey, 2019). When learners associate new information with familiar concepts or existing knowledge, the mnemonic acts as a bridge between the known and the unknown. This process not only aids in memory recall but also fosters a more profound comprehension of the material. For instance, acronyms such as those presented earlier and initialisms are common mnemonic devices that condense information into easily remembered letters, linking abstract concepts to a more recognizable form.

Moreover, the engagement of multiple senses in mnemonic techniques enhances the overall learning experience. Many mnemonic strategies involve visual, auditory, or kinaesthetic elements, catering to diverse learning styles (Islam, 2019; Makau, 2020). By appealing to different sensory modalities, mnemonics create a more immersive learning environment, making it easier for individuals to grasp and internalize complex information. The vivid mental images and associations formed through mnemonics contribute to a richer and more interconnected understanding of the subject matter. In addition to aiding memory and sensory engagement, mnemonics can foster a deeper level of understanding by promoting active learning (Garnham & Gowers, 2023; Harris, 2022; Jaiswal, 2019). Mnemonic devices often require learners to actively participate in the creation and utilization of memory aids, turning the learning process into a dynamic and personalized experience. This active involvement not only reinforces the information but also encourages critical thinking and problem-solving skills, contributing to a more comprehensive understanding of the material.

Furthermore, mnemonics can be instrumental in breaking down complex information into more manageable chunks (Dave, 2020; Norton, 2023). By condensing and organizing content through mnemonic structures, learners can navigate through intricate details with greater ease. This process of simplification promotes a step-by-step approach to understanding, allowing individuals to build a solid foundation before tackling more advanced concepts. Mnemonics thus serve as effective tools in scaffolding learning, guiding learners from basic comprehension to more sophisticated levels of understanding (Cheriti et al., 2023; DIF, 2022; Kluger et al., 2022). Lastly, mnemonics play a crucial role in facilitating understanding by creating meaningful connections, engaging multiple senses, promoting active learning, and aiding in the organization of complex information. These cognitive tools empower learners to move beyond mere memorization, fostering a deeper and more comprehensive grasp of the subject matter. As education continues to evolve, the strategic integration of mnemonics into instructional practices holds the potential to enhance the quality and efficiency of learning experiences across diverse fields.

As this study used an intervention using pre and post intervention assessments, these assessments focused on the conceptual understanding of properties of waves among preservice NSHE teachers in Namibia. The assessment involved a detailed analysis of their performance through pre- and post-intervention multiple-choice test questions. The pre-intervention test evaluated preservice teachers' accuracy in selecting the appropriate options, and their responses to the multiple-choice questions were analysed using descriptive analysis. The aim was to assess the effectiveness of the questions in determining preservice teachers' conceptual knowledge and to identify potential patterns in the distribution of their responses. Following the intervention on the usage of mnemonics to enhance students' understanding, post-assessments were conducted to measure the impact of the mnemonic-based teaching. A comparison was made between the participants' conceptual understanding before and after the intervention, providing insights into the effectiveness of the teaching approach. This comprehensive analysis aimed to not only evaluate the preservice teachers' initial conceptual understanding of the properties of waves, but also to assess the influence of the mnemonic intervention on enhancing their understanding of waves properties in NSHE.

Theoretical analysis

The Cognitive Load Theory (CLT) serves as a robust theoretical framework for the research study on enhancing preservice teachers' conceptual understanding of properties of waves through mnemonics. CLT, proposed by John Sweller, posits that learning is influenced by the cognitive load imposed on an individual's working memory during the learning process (Sweller, 1988). In the context of the current study, the use of mnemonics as memory aids can be seen as a strategic approach to managing cognitive load. Waves, being a complex scientific concept, can impose a significant cognitive burden on preservice teachers as they strive to understand and internalize the multifaceted properties of this phenomenon.

Mnemonics, by providing systematic and organized memory prompts, can reduce extraneous cognitive load, allowing more cognitive resources to be allocated to understanding the underlying principles of waves. Moreover, CLT distinguishes between intrinsic, extraneous, and germane cognitive load (Klepsch & Seufert, 2020; Orru & Longo, 2019). Intrinsic cognitive load refers to the inherent complexity of the subject matter. By employing mnemonics, the study aims to specifically address extraneous cognitive load associated with the learning process (Skulmowski & Xu, 2022). Mnemonics can act as cognitive tools that streamline information processing and aid in memory retention, thus reducing the extraneous cognitive load linked to rote memorization and information recall. The study, situated within the framework of CLT, seeks to investigate how the judicious use of mnemonics can optimize cognitive load management, ultimately enhancing preservice teachers' conceptual understanding of wave properties.

Furthermore, the research study aligns with the principles of CLT in exploring the modality effect, which suggests that presenting information through both visual and auditory channels can enhance learning (Xie et al., 2019). Mnemonics often incorporate visual and auditory elements, creating a multimodal learning experience. By incorporating mnemonics into the classroom intervention, the study acknowledges the potential of these memory aids to cater to different sensory channels, promoting a more effective encoding of wave properties in preservice teachers' long-term memory. In essence, the CLT provides a theoretical lens through which the study can systematically analyse the impact of mnemonics on cognitive load, memory retention, and overall conceptual understanding of wave properties among preservice teachers.

RESEARCHMETHODOLOGY

This study used a quantitative research approach through pre and post intervention assessment tests (Mohajan, 2020). The study involved 30 undergraduate NSHE students enrolled in the Bachelor Honours degree in Senior Primary Education at a university in Namibia. Participants were selected through a purposive sampling method, ensuring representation across different cohorts and backgrounds (Campbell et al., 2020; Mweshi & Sakyi, 2020). Collected data included participants' age categories and their gender. Undergraduate students majoring in NSHE with a focus on properties of waves in physics, currently enrolled in this qualification and in their final year were thus purposively selected. The study utilised a classroom intervention approach, with pre and post intervention of 20 multiple choice question assessments and incorporating mnemonics to enhance conceptual understanding of properties of waves.

Pre-Intervention Assessment

Prior to the intervention, NSHE preservice teachers underwent a pre-assessment using 20 multiple-choice questions designed to gauge their baseline knowledge of wave properties. These questions covered key concepts related to waves, including definitions, characteristics, and mathematical principles. The results of the pre-intervention assessment provided a benchmark to understand the initial level of understanding waves properties among NSHE preservice teachers.

Mnemonic Intervention

Following the pre-assessment test, the mnemonics intervention was implemented in the NSHE classroom. Mnemonics designed to aid memory and understanding of wave properties were introduced and integrated into the teaching methodology. Particularly, the researcher's developed "TIL and LaPf" and other mnemonics used in the teaching of physics were integrated in the teaching of wave properties. Moreover, the intervention included collaborative learning activities, mnemonic-based exercises, and classroom discussions to reinforce the use of mnemonics as memory aids for complex wave-related concepts. Mnemonics were developed based on identified conceptual challenges. These memory aids were integrated into regular classroom sessions and activities where NSHE preservice teachers were engagement in were recorded and responses were documented.

Post-Intervention Assessment

After the completion of the intervention period, NSHE preservice teachers underwent a post-assessment using multiple-choice questions similar and aligned with the pre-intervention assessment. These questions covered the same content areas to allow for a direct comparison of results. Post-intervention assessment measured the impact of mnemonics on conceptual understanding of NSHE preservice teachers in the topic of properties of waves in physic. Any significant improvement in post-intervention scores compared to pre-intervention scores would suggest the efficacy of the mnemonic-based intervention.

Data Analysis

Data analysis was employed to compare pre- and post-assessment scores. The analysis of results involved quantitative methods to examine changes in individual preservice teachers' performance. Descriptive statistics, such as means and standard deviations, have been calculated for both pre- and post-intervention scores. Additionally, inferential statistical tests, such as paired t-tests, were employed to determine if the observed differences in scores were statistically significant. The focus of this analysis was to identify whether the mnemonics intervention led to a statistically significant improvement in preservice teachers' conceptual understanding of wave properties. Descriptive statistics were consequently used to summarize demographic data and characterize the sample.

FINDINGS AND DISCUSSION

The study's findings provided valuable insights into how mnemonics can improve preservice teachers' conceptual grasp of wave features. The initial assessment before the intervention showed that NSHE preservice teachers had different levels of comprehension about wave properties (Vollebregt, 2020). Some participants showed a strong awareness of key concepts, while others had deficiencies in their knowledge, especially in wave definitions, characteristics, and mathematical principles. This initial assessment highlighted the need for specific initiatives to tackle these areas of insufficient knowledge. After the mnemonic intervention was applied, significant enhancements were noted in the post-intervention evaluation scores of NSHE preservice teachers, with a mean of 4.50 ($n = 30$; $SD = 0.65$) and a consistent standard deviation. By including mnemonics into the teaching approach and engaging students in collaborative learning activities and classroom discussions, participants achieved a deeper comprehension of wave features. Mnemonic-based exercises were thus successful in helping preservice teachers remember and apply complicated concepts more easily. Mnemonics can enhance the recall and comprehension of abstract scientific principles, especially in teacher education.

Moreover, the study also found specific mnemonic tactics, like the "TIL and LaPF" mnemonics introduced earlier in this study, to be especially helpful in remembering wave properties. The mnemonic devices were customised to tackle the conceptual difficulties observed in NSHE preservice teachers, offering specific assistance in areas of deficient comprehension. Teachers were able to strengthen important concepts and promote greater engagement with the subject matter by including these memory aides into regular classroom sessions. The study emphasises the significance of integrating collaborative learning activities into mnemonic remedies (Fuller et al., 2020). Through promoting peer engagement and conversation, preservice teachers might share ideas, resolve misunderstandings, and strengthen their comprehension of wave properties. This collaborative method improved individual learning results and created a supportive learning atmosphere that encouraged information exchange and skill enhancement.

Overall, the results of the study suggest that mnemonic-based interventions can effectively enhance the conceptual understanding of properties of waves among preservice teachers. By tailoring mnemonic strategies to address specific conceptual challenges and integrating them into classroom instruction, teachers can support the development of a more robust understanding of scientific principles. These findings have implications for teacher education programs seeking to improve the quality of science instruction and prepare educators to effectively teach complex scientific concepts in the classroom.

The results of this intervention study provide compelling evidence that mnemonic-based teaching strategies can significantly enhance the conceptual understanding of wave properties among preservice teachers. This aligns with prior findings that stress the importance of cognitive scaffolding tools in STEM education, especially in physics, where abstract concepts often hinder students' learning progression (Rouse, 2019; Nakamura, 2022). The structured mnemonic aids—such as TIL and LaPf—not only supported memory recall but also bridged theoretical understanding with perceptual interpretation of wave phenomena.

Beyond content retention, the findings also reinforce the utility of mnemonic techniques in managing cognitive load during instruction, as outlined in the Cognitive Load Theory (Sweller, 1988; Klepsch & Seufert, 2020). By minimizing extraneous processing and promoting germane load, mnemonics allowed preservice teachers to focus on constructing meaningful understanding. Furthermore, the post-intervention improvements suggest that combining visual cues, peer discussion, and active learning activities significantly strengthens the impact of mnemonic devices on learning complex concepts like frequency, amplitude, and wave propagation.

Finally, this study contributes to science teacher education by offering a replicable pedagogical model for enhancing physics instruction. As previous literature has noted, preservice teachers often enter classrooms with fragmented understandings of key scientific principles (Olaniyan, 2022). By addressing this gap through evidence-based mnemonic strategies, the study provides actionable insights for teacher training programs aiming to raise the effectiveness of physics education. Future research may expand on this approach by testing long-term retention and applicability across other science domains.

CONCLUSION

This study has offered useful insights into how mnemonics can improve preservice teachers' understanding of wave properties. The pre-assessment test highlighted the varying levels of understanding among NSHE preservice teachers on wave properties, showing both strengths and weaknesses, especially in wave definitions, properties, and mathematical principles. The findings emphasised the need for specific interventions to target areas with inadequate knowledge. After using mnemonic interventions, there were notable enhancements in the evaluation scores of NSHE preservice teachers. Integrating mnemonics into the teaching method, together with collaborative learning tasks and classroom discussions, helped participants achieve a more profound understanding of wave characteristics. Mnemonic interventions were beneficial in helping preservice teachers remember and apply complicated concepts more successfully, improving their recall and understanding of abstract scientific principles, particularly in teacher education.

Specific mnemonic strategies, like the "TIL and LaPF" mnemonics, were found to be especially helpful in improving the memory of wave properties. The mnemonic devices were customised to target and assist NSHE preservice teachers in areas where they struggled with understanding, particularly in remembering which wave properly is responsible for loudness and pitch of sound. The study highlighted the significance of incorporating collaborative learning activities into mnemonic interventions. By fostering peer involvement and conversation, preservice teachers enhanced their understanding of wave characteristics through idea exchange, clarification of ambiguities, and strengthening comprehension. This collaborative method enhanced individual learning results and promoted a supportive learning atmosphere that facilitated information sharing and skill development.

Eventually, this study's results indicate that mnemonic-based interventions can significantly improve preservice teachers' comprehension of wave properties. Teachers can enhance learners' conception of scientific principles by customising mnemonic procedures to target particular conceptual difficulties and incorporating them into classroom teaching. This research has important implications for teacher training programmes that seek to improve the quality of science teaching and equip preservice teachers with essential skills to effectively teach complex scientific ideas in the classroom.

Recommendations

Based on the findings emanating from this study, the following recommendations are made:

- The study suggests that incorporating mnemonic strategies, such as the "TIL and LaPF" mnemonic, tailored to address specific conceptual challenges can significantly improve preservice teachers' understanding of wave properties. Teachers should consider customizing mnemonic interventions to target areas where learners struggle the most, particularly in remembering complex concepts related to wave definitions, properties, and mathematical principles.
- Integrating collaborative learning activities alongside mnemonic interventions proved to be effective in enhancing preservice teachers' comprehension of wave characteristics. teachers should encourage peer interaction and discussion to promote idea exchange, clarification of ambiguities, and strengthen comprehension. Collaborative learning fosters a supportive learning environment conducive to information sharing and skill development, ultimately enhancing individual learning outcomes.
- The findings underscore the importance of incorporating mnemonic-based interventions into teacher education programs to improve the quality of science instruction. Teacher training programs should equip preservice teachers with essential mnemonic techniques tailored to address conceptual difficulties in scientific subjects. By integrating mnemonic strategies into classroom teaching, teachers can effectively enhance preservice teachers' ability to teach complex scientific concepts, ensuring they are better prepared to facilitate meaningful learning experiences for their future learners.

REFERENCES

Akhter, N., Nawshin, N., & Khatun, M. (2021). Mnemonic Techniques: Characteristics, Educational Suitability and Research Prospects in the Field of Anatomy. *Mymensingh Med J, 30*(4).

Akpan, J., Notar, C. E., & Beard, L. (2021). The impact of mnemonics as instructional tool. *Journal of Education and Human Development, 10*(3), 20-28.

Akuma, F. V., & Callaghan, R. (2019). Teaching practices linked to the implementation of inquiry-based practical work in certain science classrooms. *Journal of Research in Science Teaching, 56*(1), 64-90.

Al-Maqbali, F., Ambusaidi, A., Shahat, M., & Al Kharusi, H. (2022). The Effect Of Teaching Science Based On Mnemonics In Reducing The Sixth-Grade Female Students'cognitive Load According To Their Imagery Style. *Journal of Positive School Psychology, 6*(7), 2069-2084.

Amin, U., Nascimento, F. A., Karakis, I., Schomer, D., & Benbadis, S. R. (2023). Normal variants and artifacts: importance in EEG interpretation. *Epileptic Disorders, 25*(5), 591-648.

Anderson, N. D. (2019). State of the science on mild cognitive impairment (MCI). *CNS spectrums, 24*(1), 78-87.

Argudo, D., & Oh, T. (2022). A new framework to study the wave motion of flexible strings in the undergraduate classroom using linear elastic theory. *European Journal of Physics Education, 13*(2), 10-29.

Auliya, U. H. (2023). *The Use of Mnemonic Technique in Increasing Students" English Vocabulary Mastery at the Tenth Grade Students of SMKS Muhammadiyah Marawol* Universitas Islam Negeri Datokarama Palu].

Baddeley, A. (2020). Working memory. In *Memory* (pp. 71-111). Routledge.

Barile, C., Casavola, C., Pappalettera, G., & Paramsamy Kannan, V. (2023). Propagation of Sound Waves. In *Sound Waves and Acoustic Emission* (pp. 9-33). Springer.

Bein, O., Plotkin, N. A., & Davachi, L. (2021). Mnemonic prediction errors promote detailed memories. *Learning & Memory, 28*(11), 422-434.

Bennett, C. A. (2022). *Principles of physical optics*. John Wiley & Sons.

Berki, B. (2019). Does effective use of MaxWhere VR relate to the individual spatial memory and mental rotation skills? *Acta Polytechnica Hungarica, 16*(6), 41-53.

Branaghan, R. J., O'Brian, J. S., Hildebrand, E. A., Foster, L. B., Branaghan, R. J., O'Brian, J. S., Hildebrand, E. A., & Foster, L. B. (2021). Visual Perception. *Humanizing Healthcare–Human Factors for Medical Device Design*, 97-134.

Braun, V., Blackmore, J., Cleveland, R. O., & Butler, C. R. (2020). Transcranial ultrasound stimulation in humans is associated with an auditory confound that can be effectively masked. *Brain stimulation, 13*(6), 1527-1534.

Bravou, V., & Drigas, A. (2019). A contemporary view on online and web tools for students with sensory & learning disabilities.

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of research in Nursing, 25*(8), 652-661.

Caplan, J. B., Legge, E. L., Cheng, B., & Madan, C. R. (2019). Effectiveness of the method of loci is only minimally related to factors that should influence imagined navigation. *Quarterly Journal of Experimental Psychology, 72*(10), 2541-2553.

Casparian, A. S., & Sirokman, G. (2016). *Applied Chemistry for Environmental Engineering*. Momentum Press.

Cheriti, A., Bousdira, N., & Bounar, F. (2023). *Investigating EFL Teachers' Perspectives on the Use of Mnemonics in Teaching Phrasal Verbs The Case of EFL Teachers at Mohammed Seddik Ben Yahia*

Cioca, L.-I., & Nerișanu, R. A. (2020). Enhancing creativity: Using visual mnemonic devices in the teaching process in order to develop creativity in students. *Sustainability, 12*(5), 1985.

Çolak, K., & Aydın, R. İ. (2022). The effect of using mnemonics on success in social studies. *The Journal of Educational Research, 115*(3), 223-233.

Cowan, E. T., Schapiro, A. C., Dunsmoor, J. E., & Murty, V. P. (2021). Memory consolidation as an adaptive process. *Psychonomic Bulletin & Review*, 1-15.

Cowan, N., Morey, C. C., & Naveh-Benjamin, M. (2020). An embedded-processes approach to working memory. *Working Memory: The state of the science, 44*.

Dave, A. (2020). Does It Function? Adapting visual mnemonics and self-regulated strategy instruction to teach argumentative writing. *IAAR Journal of Education-ISSN: 2583-6846 Peer-Reviewed Journal, 2*(1), 175-233.

Devkota, G. (2019). THE PSYCHOACOUSTIC PROPERTIES OF SOUND: AN INTRODUCTION. *Indian Journal of Scientific Research, 10*(1), 215-221.

Diaz-Orueta, U., Rogers, B. M., Blanco-Campal, A., & Burke, T. (2022). The challenge of neuropsychological assessment of visual/visuo-spatial memory: A critical, historical review, and lessons for the present and future. *Frontiers in psychology, 13*, 962025.

DIF, K. (2022). *The effect of scaffolding technique to develop EFLstudents' readingcomprehensionofshort stories* KASDI MERBAH OUARGLA UNIVERSITY].

Drigas, A., Mitsea, E., & Skianis, C. (2022). Metamemory: Metacognitive Strategies for Improved Memory Operations and the Role of VR and Mobiles. *Behavioral Sciences, 12*(11), 450.

Drushlyak, M., Semenikhina, O. V., Proshkin, V. V., & Sapozhnykov, S. V. (2021). Training pre-service mathematics teacher to use mnemonic techniques. Journal of Physics: Conference Series,

Elsisi, E. (2023). AFL Students' Perception of Using Mnemonics as a Strategy to Enhance their Vocabulary Acquisition and Retention.

Farrokh, P., Vaezi, H., & Ghadimi, H. (2021). Visual Mnemonic Technique: An Effective Learning Strategy. *GIST–Education and Learning Research Journal, 23*, 7-32.

Fitzgerald, M., Danaia, L., & McKinnon, D. H. (2019). Barriers inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters. *Research in science education, 49*, 543-566.

Fuller, M. C., Ura, S. K., & Vannest, K. J. (2020). Improving cooperation skills through a mnemonic for self-monitoring. *Intervention in School and Clinic, 55*(5), 294-300.

Garnham, W. A., & Gowers, I. R. (2023). *Active Learning in Higher Education: Theoretical Considerations and Perspectives*. Taylor & Francis.

Gockel, H. E., Moore, B. C., & Carlyon, R. P. (2020). Pitch perception at very high frequencies: On psychometric functions and integration of frequency information. *The Journal of the Acoustical Society of America, 148*(5), 3322-3333.

Greve, A., Cooper, E., Tibon, R., & Henson, R. N. (2019). Knowledge is power: Prior knowledge aids memory for both congruent and incongruent events, but in different ways. *Journal of Experimental Psychology: General, 148*(2), 325.

Harris, C. (2022). Active learning. In *Learning to Teach in the Secondary School* (pp. 309-326). Routledge.

Hartman, J. R., & Nelson, E. A. (2021). A paradigm shift: the implications of working memory limits for physics and chemistry instruction. *arXiv preprint arXiv:2102.00454*.

Hill, A. C. (2022). The Effectiveness of Mnemonic Devices for ESL Vocabulary Retention. *English Language Teaching, 15*(4), 6-15.

Howell, R. A. (2021). Engaging students in education for sustainable development: The benefits of active learning, reflective practices and flipped classroom pedagogies. *Journal of Cleaner Production, 325*, 129318.

Iliaki, G., Velentzas, A., Michailidi, E., & Stavrou, D. (2019). Exploring the music: a teaching-learning sequence about sound in authentic settings. *Research in Science & Technological Education, 37*(2), 218-238.

Islam, N. (2019). Learning styles: Diverse avenues to learning. *International Journal of Research in Engineering, IT and Social Sciences, 9*(01), 73-85.

Jaiswal, P. (2019). Using learner-centered instructional approach to foster students' performances. *Theory and Practice in Language Studies, 9*(9), 1074-1080.

Jesionkowska, J., Wild, F., & Deval, Y. (2020). Active learning augmented reality for STEAM education—A case study. *Education Sciences, 10*(8), 198.

Johnson, R., Ginsberg, S., & Wilks-Smith, N. (2020). Enhancing memory for learning: Teachers' journeys of implementing memory strategies in their classrooms. *Scan: The Journal for Educators, 39*(1), 2-14.

Jones, W. E., Benge, J. F., & Scullin, M. K. (2021). Preserving prospective memory in daily life: A systematic review and meta-analysis of mnemonic strategy, cognitive training, external memory aid, and combination interventions. *Neuropsychology, 35*(1), 123.

Kılıç, F., & Yolbulan Okan, E. (2021). Storytelling and narrative tools in award-winning advertisements in Turkey: an interdisciplinary approach. *Journal of Marketing Communications, 27*(8), 881-896.

Klepsch, M., & Seufert, T. (2020). Understanding instructional design effects by differentiated measurement of intrinsic, extraneous, and germane cognitive load. *Instructional Science, 48*(1), 45-77.

Kluger, F. E., Oladimeji, D. M., Tan, Y., Brown, N. R., & Caplan, J. B. (2022). Mnemonic scaffolds vary in effectiveness for serial recall. *Memory, 30*(7), 869-894.

Kurniarahman, I. (2023). Mnemonics and Their Effect on Students' Vocabulary Memorization and Recall: A Quantitative Study. *BATARA DIDI: English Language Journal, 2*(1), 10-24.

Lass, N. J., & Donai, J. J. (2021). *Hearing science fundamentals*. Plural Publishing.

Liao, Y.-H., Kung, W.-C., & Chen, H.-C. (2019). Testing the effectiveness of creative map mnemonic strategies in a geography class. *Instructional Science, 47*, 589-608.

Lombardi, D., Shipley, T. F., Astronomy Team, B. T., Chemistry Team, Engineering Team, Geography Team, Geoscience Team,, & Team, P. (2021). The curious construct of active learning. *Psychological Science in the Public Interest, 22*(1), 8-43.

Makau, P. M. (2020). *Appropriateness Of Mnemonic Techniques on Learning Outcomes in Public Primary Schools in Machakos Sub-County, Kenya* Machakos University Press].

Mari-Acevedo, J., Yelvington, K., & Tatum, W. O. (2019). Normal EEG variants. *Handbook of clinical neurology, 160*, 143-160.

Mohajan, H. K. (2020). Quantitative research: A successful investigation in natural and social sciences. *Journal of Economic Development, Environment and People, 9*(4), 50-79.

Moreira, F., Ferreira, M. J., Pereira, C. S., Escudero, D. F., Collazos, C., & Gomes, A. (2021). Higher education teachers training (HET2) model: Active learning in higher education environment. World Conference on Information Systems and Technologies,

Mweshi, G. K., & Sakyi, K. (2020). Application of sampling methods for the research design. *Archives of Business Review–Vol, 8*(11).

Nakamura, N. (2022). *Theoretical Framework for Musical Mnemonics Interventions Addressing Verbal Memory* University of Kansas].

Newton, D. P. (2022). *A practical guide to teaching science in the secondary school*. Taylor & Francis.

Ni, L. B., & Hassan, N. A. B. (2019). The use of mnemonic and mathematical mnemonic method in improving historical understanding. *International Journal of Educational and Pedagogical Sciences, 13*(2), 93-97.

Norton, S. A. (2023). *Storytelling in the Classroom: How Mnemonics Impact Memory* Spalding University].

Olaniyan, A. O. (2022). Assessing Novice Preservice Physics Teachers' Conceptual Knowledge of Mechanical Waves. *International Journal of Research and Scientific Innovations (IJRSI), 9*(12), 85-93.

Orru, G., & Longo, L. (2019). The evolution of cognitive load theory and the measurement of its intrinsic, extraneous and germane loads: a review. Human Mental Workload: Models and Applications: Second International Symposium, H-WORKLOAD 2018, Amsterdam, The Netherlands, September 20-21, 2018, Revised Selected Papers 2,

Papanastasiou, G., Drigas, A., Skianis, C., Lytras, M., & Papanastasiou, E. (2019). Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. *Virtual Reality, 23*, 425-436.

Qureshi, M. A., Khaskheli, A., Qureshi, J. A., Raza, S. A., & Yousufi, S. Q. (2023). Factors affecting students' learning performance through collaborative learning and engagement. *Interactive Learning Environments, 31*(4), 2371-2391.

Radović, T., & Manzey, D. (2019). The impact of a mnemonic acronym on learning and performing a procedural task and its resilience toward interruptions. *Frontiers in psychology, 10*, 2522.

Rodrigues, A. L. (2020). Digital technologies integration in teacher education: the active teacher training model. *Journal of e-learning and knowledge society, 16*(3), 24-33.

Rodríguez-Sabiote, C., Úbeda-Sánchez, Á. M., Álvarez-Rodríguez, J., & Álvarez-Ferrándiz, D. (2020). Active learning in an environment of innovative training and sustainability. Mapping of the conceptual structure of research fronts through a bibliometric analysis. *Sustainability, 12*(19), 8012.

Røe, Y., Wojniusz, S., & Bjerke, A. H. (2022). The digital transformation of higher education teaching: four pedagogical prescriptions to move active learning pedagogy forward. Frontiers in Education,

Roheger, M., Folkerts, A.-K., Krohm, F., Skoetz, N., & Kalbe, E. (2020). Prognostic factors for change in memory test performance after memory training in healthy older adults: a systematic review and outline of statistical challenges. *Diagnostic and Prognostic Research, 4*(1), 1-23.

Rouse, J. (2019). *Articulating the world: Conceptual understanding and the scientific image*. University of Chicago Press.

Rumsey, F. (2021). *Sound and recording: applications and theory*. Routledge.

Rusdiyanto, E., Munawir, A. (2023). New Built Land Threat of Martapura River – Implementation of Environmental Sustainability in Banjarmasin City, South Kalimantan, Indonesia. Journal of Ecological Engineering, 24(5), 276-287. https://doi.org/10.12911/22998993/161759

Siagian, D. T., Maida, N., Irianto, D. M., & Sukardi, R. R. (2023). The Effectiveness of Mnemonic Device Techniques in Improving Long-Term Memory in Learning in Elementary Schools: A Literature Review. *Equator Science Journal, 1*(1), 24-30.

Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. *Educational psychology review, 34*(1), 171-196.

Smith, C., & Gillespie, M. (2023). Research on professional development and teacher change: Implications for adult basic education. In *Review of Adult Learning and Literacy, Volume 7* (pp. 205-244). Routledge.

Soland, K. (2022). Does loudness represent sound intensity? *Synthese, 200*(2), 100.

Sommeillier, R., Quinlan, K. M., & Robert, F. (2021). Domain of validity framework: a new instructional theory for addressing students' preconceptions in science and engineering. *Studies in Science Education, 57*(2), 205-239.

Sperber, D. (2019). Instincts or gadgets? Not the debate we should be having. *Behavioral and Brain Sciences, 42*.

Steiglitz, K. (2020). *Digital Signal Processing Primer*. Courier Dover Publications.

Stinken-Rösner, L., Rott, L., Hundertmark, S., Baumann, T., Menthe, J., Hoffmann, T., Nehring, A., & Abels, S. (2020). Thinking inclusive science education from two perspectives: Inclusive pedagogy and science education. *Research in Subject-matter Teaching and Learning (RISTAL), 3*(1), 30-45.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive science, 12*(2), 257-285.

Szőllősi, Á., & Racsmány, M. (2020). Enhanced mnemonic discrimination for emotional memories: the role of arousal in interference resolution. *Memory & cognition, 48*, 1032-1045.

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., & Dunster, G. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences, 117*(12), 6476-6483.

Tomczak, E., & Lew, R. (2019). The song of words": Teaching multi-word units with songs. *3L: The Southeast Asian Journal of English Language Studies, 25*(4), 16-33.

Tullis, J. G., & Qiu, J. (2022). Generating mnemonics boosts recall of chemistry information. *Journal of Experimental Psychology: Applied, 28*(1), 71.

Vollebregt, B. R. (2020). *The effect of training in equipment use on science teachers' PCK about the wave concept* University of Pretoria].

Wanner, P., Cheng, F.-H., & Steib, S. (2020). Effects of acute cardiovascular exercise on motor memory encoding and consolidation: A systematic review with meta-analysis. *Neuroscience & Biobehavioral Reviews, 116*, 365-381.

Webster, O. (1966). Read well and remember: a guide to more rapid, more efficient reading. *(No Title)*.

Weinberger, N., & Merhav, N. (2022). The DNA storage channel: Capacity and error probability bounds. *IEEE Transactions on Information Theory, 68*(9), 5657-5700.

Whiting, J. K., Berardi, M. L., Vaughn, A. B., Vongsawad, C. T., Neilsen, T. B., Anderson, B. E., & Gee, K. L. (2022). Sounds to astound: An acoustics outreach show. *The Journal of the Acoustical Society of America, 152*(2), 835-850.

Williams, J. J. (2022). *The Use of Musical Mnemonic Devices in the Aid of Short-Term and Long-Term Memory Recall* Indiana State University].

Xi, X., Teng, H., Chen, Z., & Yang, P. (2022). Effects of longitudinal disturbances on two-dimensional detonation waves. *Physical Review Fluids, 7*(4), 043201.

Xie, H., Mayer, R. E., Wang, F., & Zhou, Z. (2019). Coordinating visual and auditory cueing in multimedia learning. *Journal of Educational Psychology, 111*(2), 235.