

# A Review of Research on the Sape: Acoustic Properties, Cultural Significance, and Modern Developments

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The sape is a traditional stringed instrument of the indigenous communities of Borneo that has evolved from its ritual origins into a symbol of cultural identity and contemporary relevance. This review examines more than 25 academic works across ethnomusicology, acoustic and engineering studies, soundboard quality and machine learning, music education, and health-related research. Existing studies address topics ranging from tonal behaviour and material assessment to cultural heritage, pedagogy, and therapeutic applications. While the literature demonstrates growing interdisciplinary interest, significant gaps remain, particularly in indigenous participation, documentation of traditional repertoires, and integration across research domains. This review highlights the need for culturally grounded and community-engaged approaches to support the continued transmission and sustainability of the sape.

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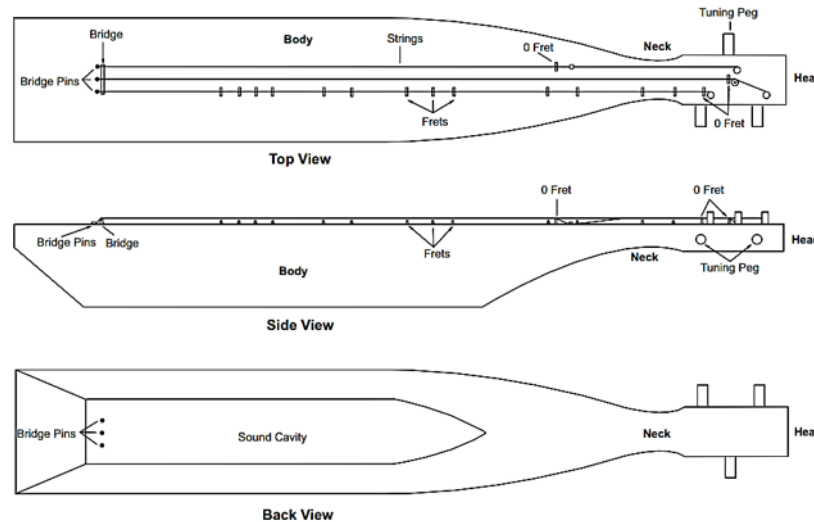
## INTRODUCTION

The sape, also known as sapeh, sapek, or sampe, is a traditional lute-like stringed instrument indigenous to the Orang Ulu communities of Borneo, particularly among the Kenyah, Kayan, and Kelabit ethnic groups in Sarawak, Malaysia, and parts of Kalimantan, Indonesia (see Fig. 1). Originally associated with ritual and healing practices, the sape has experienced substantial musical and cultural transformations, evolving from a sacred instrument into a widely recognised symbol of cultural identity and musical expression across the region.

In recent decades, there has been a growing global interest in traditional musical instruments, spurred by cultural preservation efforts, ethnomusicological scholarship, and technological advancements in sound analysis. In parallel, the sape has emerged as a subject of interdisciplinary study, attracting researchers from fields such as acoustics, material science, anthropology, and digital humanities. As the instrument gains prominence on international stages and is increasingly incorporated into contemporary music genres, understanding its acoustical properties, construction methods, and cultural evolution becomes imperative.

Scientific investigations into the sape have covered a range of topics, including the influence of wood type and structural design on sound quality, the classification of sape tones using machine learning techniques, and the finite element modelling of vibration modes. These studies aim to bridge traditional knowledge with modern analytical tools,

allowing for better documentation, preservation, and enhancement of the instrument. At the same time, research on the cultural dimensions of the sape explores its significance in oral traditions, performance practices, and identity formation among indigenous communities.



**Fig. 1.** Schematic drawing of sape

Despite this emerging body of work, there has remained a lack of a comprehensive review that consolidates existing findings and identifies opportunities for future research. This paper aims to address that gap by providing a critical synthesis of past and current studies on the sape musical instrument. Specifically, it examines contributions related to acoustic analysis, craftsmanship and material selection, technological integration, and cultural scholarship. By doing so, this review not only charts the trajectory of sape-related research but also highlights its potential as a subject of ongoing multidisciplinary inquiry.

To ensure transparency in the review process, this study adopts a narrative approach by synthesising more than 25 academic works on the sape published between approximately 2010 and 2025. Relevant literature was identified through major academic databases, including Scopus, Web of Science, and Google Scholar, using keywords such as “sape”, “sapeh”, “Borneo lute”, “acoustic analysis”, and “ethnomusicology”. Additional sources were obtained through reference tracking of key publications. Studies were selected based on their relevance to the instrument’s acoustical properties, cultural significance, craftsmanship, pedagogy, and technological development. Both peer-reviewed journal articles and conference proceedings published in English and Malay were included to ensure comprehensive coverage of interdisciplinary research on the sape.

It should be noted that several of the technical studies discussed in this review are contributed by the author. These works are contextualised within the broader body of literature to ensure a balanced and critical synthesis of existing research.

## THEMATIC REVIEW OF SAPE RESEARCH

Over the past two decades, academic interest in the sape has expanded across multiple disciplines, reflecting the instrument’s cultural significance, evolving pedagogical roles, and growing engagement with scientific, technological, and health-related research.

The number of publications related to the sape has gradually increased over time, with a more noticeable concentration of studies published after 2015, indicating growing interdisciplinary attention to the instrument. To synthesise this diverse body of work, this review organises existing studies into eight thematic areas: craftsmanship and instrument making, religious and ritual use, ethnomusicology and cultural heritage, music education and learning, music therapy and health applications, acoustic studies and engineering, soundboard quality and machine learning, and digitalisation and technological innovation. Each subsection critically examines representative studies in terms of their research focus, methodologies, key contributions, and limitations, providing a structured overview of how contemporary scholarship approaches the sape as both a cultural artefact and a subject of scientific inquiry.

### **Craftsmanship and the Making of the Sape**

Research on the making of the sape remains limited but provides important insight into the instrument's material construction, craftsmanship practices, and transmission of technical knowledge within Dayak communities. These studies treat the sape not merely as a finished musical artefact, but as the outcome of embodied skills, material selection, and culturally informed design decisions.

One of the few studies that explicitly documents the sape-making process is the community-based work by Rusdi and Wibowo (2023), which examines the production of traditional sape instruments in Desa Dedai Kanan, Sintang, West Kalimantan. Their study outlines key stages in sape construction, including the selection of suitable hardwood, shaping of the instrument body, carving and finishing processes, and aesthetic considerations aligned with traditional motifs. Importantly, the authors highlight that material selection and craftsmanship are closely linked to both sound quality and cultural value, reinforcing the role of experienced artisans in maintaining construction standards.

Beyond technical description, Rusdi and Wibowo (2023) emphasise the role of sape making as a form of cultural transmission and economic empowerment. Through hands-on workshops, younger community members are introduced to traditional construction techniques, fostering continuity of craftsmanship while also enabling small-scale entrepreneurship. This aligns with broader ethnomusicological observations that instrument-making knowledge is typically transmitted through apprenticeship and practice rather than formal documentation.

Complementary ethnomusicological inventories of Iban musical instruments situate the sape within a wider ecosystem of traditional craftsmanship, noting variations in size, form, and decorative features across communities (Osip 2017). However, such studies remain largely descriptive and offer limited acoustic or structural analyses of how construction choices influence sound production.

Overall, existing literature suggests that sape making is a critical but under-researched dimension of sape studies. While current works document basic construction stages and cultural significance, they lack systematic investigation into the relationships between material properties, geometric design, and acoustic performance. Future research should integrate experimental and acoustic measurements to understand better how craftsmanship influences sound quality and to support interdisciplinary approaches that combine ethnomusicology, acoustics, and engineering.

## Religious and Ritual Use

The earliest role of the sape is closely associated with indigenous belief systems and ritual practices among Orang Ulu and other Dayak communities in Sarawak. Before it emerged as a performance and entertainment instrument, the sape functioned primarily as a medium for spiritual communication, healing rites, and ceremonial expression. Traditional repertoires, including *sambe asal* and *sambe bali dayong*, were commonly linked to spirit invocation, dream narratives, and transitional rites, reflecting the worldview that music mediated interaction between the human and spiritual realms.

Ritual sape performances were governed by strict cultural conventions concerning repertoire selection, tuning systems, and performer status. These performances prioritised spiritual efficacy and ceremonial purpose rather than aesthetic display or audience entertainment. Improvisation, while present, was carefully guided by ritual intention and cosmological symbolism, reinforcing the instrument's sacred significance within the community.

With the spread of Christianity and broader socio-cultural change in Sarawak, the ritual functions of the sape gradually declined or were recontextualised. In many cases, the instrument was adapted for church-related activities and cultural festivals, where symbolic and stylistic elements were retained but detached from their original ritual meanings. Understanding these religious and ritual origins is therefore essential for interpreting later developments in sape repertoire, performance practice, and pedagogy. Contemporary ethnomusicological studies have increasingly focused on how the cultural meanings and social functions of the sape have been transformed as it continues to evolve within changing religious and social contexts.

In addition to its pre-Christian ritual significance, recent studies demonstrate that the sape has undergone a process of religious recontextualization within contemporary Christian worship. A qualitative study by Kiring (2023) examines the incorporation of the sape into liturgical practices at the Gereja Kemah Injil Indonesia in North Kalimantan, illustrating how an instrument once associated with indigenous ritual and spiritual mediation is adapted for church worship. Drawing on interviews and participant observation, the study shows that the sape is employed as an accompaniment for congregational singing through deliberate processes of liturgical revision and indigenisation, including the adjustment of song keys, melodic structures, and the translation of hymn lyrics into local Dayak languages. Rather than reviving its former ritual functions, the sape is reinterpreted as a culturally resonant medium for Christian praise, enabling congregants to engage more deeply with worship while preserving local musical identity. This case highlights how the sacred associations of the sape are not erased but transformed, reinforcing its continued spiritual relevance within evolving religious contexts and supporting broader discussions on the adaptation of ritual instruments in post-conversion societies.

Recent ethnomusicological work further demonstrates that the sacred dimensions of the sape may persist through processes of reinterpretation rather than disappearance. Syahputra *et al.* (2024) examine the continued ritual use of sape' *karaang* in the Hudo' ritual among the Dayak Bahau community in Samarinda, despite the community's shift away from animist belief systems. Their study shows that traditional leaders play a central role in reinterpreting earlier animist sources of sacredness into more universal religious meanings, allowing the sape to retain ritual legitimacy within a transformed belief framework. This case reinforces the view that the sape's sacred significance is not fixed, but dynamically renegotiated in response to religious and socio-cultural change.

While these studies provide valuable insights into the evolving cultural and spiritual roles of the sape, they rely primarily on qualitative observations and are often limited to single-case analyses. The absence of comparative or longitudinal approaches restricts a broader understanding of how such reinterpretations vary across communities and over time. Future research should therefore adopt more systematic and cross-cultural methodologies to better capture the dynamics of continuity and transformation in sape-related practices.

### **Ethnomusicology and Cultural Heritage**

Ethnomusicological research on the sape provides essential insight into its cultural significance, traditional functions, and social transformations within indigenous communities. These studies examine the sape not merely as a musical instrument, but as a cultural practice embedded in belief systems, social organisation, and processes of change.

Lim and Abdul Rahman (2016) provided a foundational ethnographic overview tracing the historical development and changing roles of the sape. Their paper documents the evolution of the instrument from its traditional settings within longhouse communities to its emergence on international stages. While their work effectively captures the adaptive transformations of the sape and its contemporary significance, it remains largely descriptive, lacking deeper critical analysis regarding the implications of global exposure and potential cultural commodification.

Lim *et al.* (2016) provide a comprehensive documentation of the sape as a traditional musical instrument of Sarawak, combining historical background, construction features, tuning systems, repertoire, and performance contexts. Published by Dewan Bahasa dan Pustaka, the work serves as an important reference text that consolidates indigenous knowledge and institutional scholarship on the sape, contributing to its recognition as a cultural heritage artefact. In addition, traditional sape instruments are preserved in regional museum collections, including the Borneo Cultural Museum, where they serve as important references for historical design, craftsmanship, and cultural documentation. While primarily descriptive in nature, the book plays a significant role in preserving foundational knowledge about the instrument and offers an essential baseline for subsequent ethnomusicological, acoustic, and educational studies.

Extending the discussion of cultural continuity and transformation, Hartanto *et al.* (2021) examine the sape within modernist frameworks among the Dayak Kayaan community. Their ethnographic findings reveal tensions between preserving inherited cultural values and embracing innovation, particularly as the sape increasingly functions as an entertainment and identity symbol. However, the study primarily operates at a sociocultural level and would benefit from deeper engagement with musical structure, performance practice, or repertoire change.

A heritage-oriented perspective is offered by Syam *et al.* (2024), who conceptualise the sape as a medium for preserving civic culture and local wisdom. Using a phenomenological approach, the authors frame the sape as both a cultural symbol and a vehicle for transmitting communal values across generations. They introduce the concept of glocalization, arguing that digital dissemination and creative adaptation enable the sape to remain culturally grounded while engaging with global audiences. While this study contributes important insights into cultural preservation and identity politics, its emphasis on symbolic and civic values somewhat overshadows a detailed ethnomusicological analysis of musical structure and sound production.

Complementing these interpretive studies, Osup (2017) provides a systematic ethnomusicological inventory of Iban musical culture in Sarawak, situating the sape within a wider ensemble of percussion, string, and wind instruments. Through detailed documentation of instrument types, ritual functions, and performance contexts, the study highlights the sape's role alongside gongs and drums in ceremonial and social settings. Notably, Osup (2017) identifies a decline in intergenerational transmission, particularly among younger community members, underscoring the vulnerability of traditional musical knowledge amid modernisation. Although primarily descriptive, this work offers an essential empirical foundation for understanding the sape's place within Iban musical heritage.

Taken together, these studies present the sape as a dynamic cultural expression shaped by historical continuity, social change, and evolving identity. Ethnomusicological perspectives reveal not only how the sape functions musically, but also how it operates as a cultural symbol, heritage resource, and site of negotiation between tradition and modernity. This body of work underscores the importance of integrating ethnographic, cultural, and musical analyses to fully understand the sape's role within both local communities and broader cultural landscapes.

However, despite these contributions, many studies remain largely descriptive and provide limited analysis of musical structure, performance techniques, or sonic characteristics. This restricts a deeper understanding of the relationship between cultural context and musical practice. Future research would benefit from integrating ethnographic approaches with detailed musical and acoustic analysis to achieve a more comprehensive and interdisciplinary perspective.

At the same time, the sape continues to evolve within contemporary musical contexts, where it is increasingly incorporated into modern and fusion genres. Performers such as Alena Murang and Jerry Kamit have brought the instrument to international audiences, where traditional musical elements are reinterpreted within contemporary and fusion contexts (Lim *et al.* 2016). This reflects a process of cultural continuity through innovation, rather than a shift away from tradition.

## Music Education and Learning

As the sape gains wider recognition beyond its indigenous origins, efforts to transmit playing techniques and musical knowledge have increasingly shifted from oral tradition toward more structured educational and documentation-based approaches. Research in this area reflects growing concern for pedagogy, preservation, and accessibility, particularly for younger learners and institutional settings.

Chong (2013) demonstrates that Kenyah recreational songs, often accompanied by the sape, have strong pedagogical value due to their predominantly pentatonic structures, rhythmic consistency, and integration of music and movement. Based on extensive ethnographic fieldwork and classroom application, the study shows that these materials can be effectively incorporated into formal music education, including Kodály- and Orff-based approaches, even among students unfamiliar with the Kenyah language, supporting culturally responsive music pedagogy and heritage transmission.

Hashim (2024) published *7 Fundamental Techniques for Playing Sape*, a practical guide designed for beginners. The book introduces essential skills such as tuning, posture, plucking technique, rhythmic control, and basic melodic phrasing. Written for a young student audience, it emphasises clarity and ease of learning through step-by-step visuals and culturally relevant examples. By formalising instructional content that was

traditionally transmitted orally, the guide contributes meaningfully to the continuity of sape practice among new generations.

Analytical and documentation-oriented studies have also supported music education by transforming traditional repertoires into structured learning resources. Sudom and Naili (2022) conducted a detailed musical analysis of selected Kenyah sape repertoires using score transcription and theoretical examination of melody, rhythm, and harmony. By documenting repertoires such as Leleng, Det Diet Tapung Ulat Kitan, Titiek Titiek Kenai Ujan, and Datun Julud, the study provides written references that enable systematic learning and teaching. The authors note that repetitive melodic structures and simple harmonic frameworks make these repertoires particularly suitable for educational purposes, positioning the work at the intersection of ethnomusicology and pedagogy.

In addition, Musib (2016) examined challenges in recording and preserving sape performances, identifying issues such as tonal distortion and loss of fidelity through interviews with musicians and recording practitioners. While technically focused, the study is relevant to music education in its emphasis on producing reliable learning and archival materials. Musib's doctoral research (2015) further expanded this discussion by proposing methodologies for documenting traditional string instruments and preserving authentic soundscapes. Although the thesis places limited emphasis on community participation and ethical considerations, its contribution to systematic documentation provides valuable support for educational transmission and long-term learning resources.

Nevertheless, despite these contributions, existing studies provide limited empirical evidence on learning outcomes, curriculum effectiveness, and long-term skill development. This constrains a comprehensive evaluation of pedagogical impact and the effectiveness of different teaching approaches. Future research should therefore adopt more systematic and comparative designs to assess educational outcomes across diverse learning contexts.

### **Music Therapy and Health Applications**

Beyond its cultural and musical functions, the sape has attracted increasing scholarly attention within the fields of health and wellness, particularly in relation to music therapy and stress management. Existing studies have examined its therapeutic effects on both psychological and physiological indicators, including stress, anxiety, blood pressure, and sleep quality. Collectively, this body of work positions the sape as a culturally grounded, non-pharmacological intervention that may complement conventional health and educational support systems.

In educational contexts, Hadii and Wangid (2023) demonstrated that structured sape music therapy significantly reduced stress levels among middle school students in Aceh Singkil using a pre–post intervention design. Their findings highlight the potential of sape-based music therapy as an accessible and culturally appropriate stress-regulation tool in educational environments where formal mental health resources are limited, reinforcing its applicability for adolescent mental health support.

Evidence from clinical settings further supports the broader therapeutic relevance of sape music. Syam'ani (2022) showed that guided imagery combined with sape music effectively reduced anxiety among patients undergoing hemodialysis, indicating its suitability for high-stress medical environments. Extending these findings to cardiovascular health, Palimbunga *et al.* (2023) found that sape music therapy significantly reduced systolic blood pressure among elderly patients with stage I hypertension, although changes in diastolic pressure were not statistically significant.

More robust clinical evidence is provided by Pilang *et al.* (2022), who conducted a randomised controlled trial involving post-section caesarean patients. Their study demonstrated that sape music therapy significantly reduced anxiety, pulse rate, and respiratory rate, while improving sleep quality and maintaining blood pressure within normal ranges. These results suggest that the calming acoustic characteristics of the sape may influence autonomic nervous system regulation and support postoperative recovery.

Overall, the emerging literature indicates that the sape can function not only as a cultural artefact but also as a therapeutic medium with measurable psychological and physiological benefits. While initial findings are promising, existing studies are often limited by small sample sizes, short intervention durations, and a lack of methodological diversity. These limitations constrain the robustness and generalisability of the findings. Future research should therefore employ more rigorous experimental designs, larger and more diverse populations, and longitudinal approaches to better validate the therapeutic potential of sape-based interventions.

### Acoustic Studies and Engineering

Research in this field investigates the physical and acoustic principles that govern sape sound production, including its frequency behaviour, resonance, and vibrational responses to various performance techniques. These studies form the scientific foundation for refining instrument design and understanding tonal qualities in a measurable way.

Hamdan *et al.* (2023) analysed the frequency spectrum and time frequency characteristics of the sape using digital tools and applying Fast Fourier Transform and Time Frequency Analysis. Focusing on six strings of a modern sape, including fretted and drone strings, the study documented harmonic overtones and partial frequencies across frets. While the results provide useful reference data on tonal range and overtone structure, the analysis is limited to a single instrument and remains largely descriptive, offering limited insight into performance practice or instrument design.

Further investigation into the mechanics of pitch production was presented by Wong *et al.* (2022a), who studied the effects of fret placement on fundamental frequencies. Their experimental setup measured the frequency shifts resulting from incremental fret adjustments. While the study successfully demonstrated the relationship between fret location and tonal precision, it was limited to simplified physical setups and did not account for variability in performance techniques or instrument craftsmanship. Nonetheless, it provides an empirical baseline that may inform more consistent fret design in contemporary sape construction.

In an earlier study, Wong *et al.* (2017) examined the relationship between string tension and both the fundamental frequency and body vibration of the sape. Drawing from physical vibration theory, they modelled the expected frequency responses and validated these with experimental data. The results showed that higher tension increased pitch and altered the vibration behaviour of the instrument body. While the study confirms basic acoustic principles, it stops short of integrating the findings into practical design recommendations or player guidance.

Wong and Dayou (2019) extended this line of inquiry by analysing how varying plucking forces affect both sound output and vibrational response. Through controlled plucking tests, they observed that increased force led to nonlinear changes in amplitude and frequency, revealing the dynamic acoustic effects of expressive playing. The study provides useful insights into performer-instrument interaction, though the extent to which these findings generalise across sape models and players remains unclear.

Wong (2024), in his doctoral dissertation, applied a more integrative framework to assess soundboard wood quality using engineering tests and machine learning. Free-free beam vibration experiments were used to extract acoustic features such as loudness, period, and timbre, which were then fed into classification models to rank wood suitability for sape making. While the approach is innovative, the study relies on a limited sample size and does not account for long-term tonal changes in real performance settings. Still, it demonstrates the potential of combining empirical analysis with data-driven methods to guide material selection and instrument construction.

Despite providing valuable quantitative insights, many studies are conducted under controlled conditions and may not fully reflect real-world performance variability. Future research should incorporate diverse instruments and player techniques to improve generalisability.

### **Soundboard Quality and Machine Learning**

The acoustic performance of the sape is fundamentally influenced by the physical and mechanical properties of the wood used, including density, stiffness, and internal damping. These parameters govern vibration behaviour, resonance characteristics, and sound radiation, directly affecting tonal quality, sustain, and projection. Understanding the relationship between wood attributes and acoustic response is therefore essential for both traditional craftsmanship and the optimisation of instrument design through scientific and data-driven approaches.

Building on this foundation, the integration of machine learning into the study of sape soundboard quality has introduced new possibilities for objective evaluation and consistency in instrument making. These studies seek to complement traditional knowledge by providing measurable, replicable metrics that can aid both researchers and artisans.

Wong *et al.* (2022b) applied Support Vector Machine (SVM) models to classify Aday, Tapang, and Merbau woods using acoustic features derived from free-free beam vibration tests. Aday was identified as the most acoustically favourable material. Despite methodological clarity, the limited dataset and narrow feature scope restrict broader generalisation. Wong (2024) expanded this approach by incorporating a wider range of spectral features and achieving high classification accuracy using a Gaussian SVM. The study demonstrates technical robustness, although validation in real instrument-making environments remains limited. Wong *et al.* (2025) extended this line of work by combining physical, vibroacoustic, and timbre features to classify the same three wood types, with decision tree and bagged tree classifiers achieving the highest accuracy (98.1%), again ranking Aday as the highest-quality soundboard wood. However, the model was not purpose-built for sape instruments, and misclassification persisted between the acoustically similar Merbau and Tapang woods.

Building on this framework, Wong (2024) expanded the analysis in his doctoral research by incorporating a broader set of audio features using MATLAB and the MIRTtoolbox, such as spectral centroid, roughness, and zero-crossing rate. Gaussian SVM was used for classification, achieving an accuracy above 90%. The study provided a detailed account of the machine learning workflow and validation process. However, the absence of real-world testing with multiple instruments and the lack of comparative data from traditional sape makers limit the direct applicability of the model in practice. Despite this, the research demonstrates the technical viability of using advanced algorithms to support material assessment in musical instrument design.

In a related contribution, Wong *et al.* (2023) conducted a timbre analysis of sape instruments through both objective spectral measurements and subjective evaluations by trained musicians. Parameters such as harmonic richness, clarity, and brightness were considered in a rubric designed to assess overall tonal quality. The study emphasised the value of integrating perceptual judgment with computational analysis. However, details about the expertise level of the evaluators and the standardisation of listening conditions were limited, which may affect reproducibility.

To improve accessibility, Wong *et al.* (2024) also developed a Graphical User Interface (GUI) that enables instrument makers to assess wood quality using uploaded audio recordings. Designed with user-friendliness in mind, the GUI translates complex computational outputs into understandable feedback. While innovative, the tool's reliance on controlled recording input raises questions about its robustness in diverse field conditions. More broadly, although machine learning approaches demonstrate high classification accuracy, their practical applicability remains constrained by small datasets and controlled experimental environments. These limitations restrict real-world implementation, and further validation in actual instrument-making contexts is needed to ensure reliability and usability.

### **Digitalisation, Virtualisation, and Technological Innovation**

Recent scholarship reflects a growing interest in the digital transformation of the sape, focusing on preservation, accessibility, education, and creative innovation. These studies collectively demonstrate how digital technologies are being employed to extend the presence of the sape beyond its traditional performance contexts while negotiating concerns related to authenticity and cultural continuity.

Several studies emphasise digitisation as a strategy for cultural preservation and knowledge democratisation. Efforts to digitally document and archive traditional Indonesian music, including the sape, aim to safeguard endangered musical knowledge and broaden public access through digital platforms (Kurniasaid and Supriyono 2018). Such initiatives position technology as a mediating tool that supports intergenerational transmission, particularly among younger audiences with high digital literacy.

Educational applications form a major strand within this body of work. Android-based applications and educational games have been developed to introduce users to the sape through interactive simulation, historical content, and basic playing techniques. Empirical evaluations of these applications indicate positive user reception and improved engagement, especially among school-aged learners, suggesting that digital interfaces can serve as effective supplementary tools for music education without replacing embodied learning practices.

Beyond education, digital sound technologies have also facilitated musical hybridisation and contemporary composition. The use of digital sound effects and minimalist aesthetics has enabled composers to integrate sape timbres into experimental and cross-genre works, expanding their sonic possibilities while raising questions about stylistic transformation and cultural framing. Similarly, the development of sape Virtual Studio Technology instruments (VSTi) allows composers and producers to incorporate sape-like sounds into digital audio workstations without physical instruments. While such tools offer efficiency and global reach, ethnomusicological analyses indicate that they cannot fully replicate the expressive nuance, performance context, or cultural meaning of the original instrument, and are therefore best understood as complementary rather than substitutive technologies.

Taken together, these studies suggest that digitalisation has reshaped how the sape is learned, disseminated, and creatively reimagined. Rather than signalling cultural erosion, technological engagement appears to support adaptive continuity, enabling the sape to remain relevant within contemporary educational, creative, and digital ecosystems. However, despite these benefits, the impact of digital technologies on authenticity, performance practice, and cultural meaning remains underexplored. This raises important questions regarding performer agency and the balance between technological convenience and cultural integrity. Future research should therefore critically examine these dimensions to ensure that digital innovation supports, rather than compromises, the cultural essence of the sape.

## RESEARCH GAP AND FUTURE DIRECTIONS

Despite increasing scholarly attention, research on the sape remains fragmented across disciplinary boundaries and uneven in methodological depth. While individual studies have advanced understanding in areas such as acoustics, pedagogy, cultural heritage, and therapeutic application, there is limited integration between technical, ethnomusicological, and community-based perspectives.

A major gap lies in the disconnect between scientific studies, particularly in acoustics, engineering, machine learning, and indigenous knowledge systems embedded in traditional sape making and performance practice. Quantitative analyses of vibration, frequency response, and material properties often operate independently of ethnographic insights related to craftsmanship, tuning conventions, repertoire, and cultural meaning. Future research would benefit from interdisciplinary frameworks that combine empirical measurement with ethnomusicological fieldwork and indigenous epistemologies.

Another limitation concerns the under-representation of indigenous voices in the research process. Many studies are conducted from external academic perspectives, with limited collaboration with Dayak musicians, instrument makers, and cultural custodians. Greater emphasis on participatory and community-engaged research would enhance cultural authenticity, ethical rigour, and practical relevance, particularly in studies involving documentation, digitalisation, and technological intervention.

In music education and preservation, existing studies have contributed significantly through instructional materials, transcription, and documentation. Nevertheless, systematic research on learning outcomes, curriculum integration, and comparative pedagogical approaches is still limited. Coordinated initiatives to document and archive repertoires, tuning systems, and performance techniques, many of which continue to be transmitted orally, are crucial for safeguarding intangible cultural heritage.

Although early findings in music therapy suggest that sape music may contribute to stress reduction, anxiety management, and physiological regulation, existing studies are limited in scale, duration, and population diversity. More rigorous experimental designs, longitudinal studies, and cross-cultural comparisons are needed to substantiate therapeutic claims and clarify underlying mechanisms.

Finally, while digitalisation and virtualisation have expanded access and creative possibilities, critical evaluation of their long-term cultural impact remains limited. Future work should address issues of authenticity, performer agency, and the balance between technological convenience and cultural integrity, particularly as digital tools increasingly mediate how the sape is learned, produced, and disseminated.

## CONCLUSIONS

1. The sape, originally rooted in the longhouse communities of Borneo, has evolved into a widely recognised symbol of cultural identity, artistic expression, and adaptive continuity within contemporary society.
2. This review provides a synthesis of existing scholarship on the sape across multiple research domains, including traditional craftsmanship, religious and ritual practices, ethnomusicology, music education, health-related applications, acoustics, machine learning, and digital innovation.
3. Technical studies drawing from acoustics, engineering, and data-driven methodologies have significantly advanced understanding of the sape's tonal behaviour, vibrational characteristics, and material performance, providing systematic tools for instrument design, evaluation, and quality assessment.
4. In parallel, ethnomusicological and cultural research has documented the sape's historical roles, symbolic meanings, and regional diversity, ensuring that scientific and technological investigations remain grounded in cultural context and lived musical practice.
5. Collectively, the literature demonstrates that the sape should be understood not merely as a traditional musical instrument, but as a dynamic cultural practice shaped by craftsmanship, belief systems, pedagogy, technological adaptation, and broader social change.
6. By integrating diverse strands of research into a coherent thematic framework, this review offers a consolidated reference for future scholarship and underscores the importance of sustaining the sape as both an intangible cultural heritage and an evolving site of artistic and scientific inquiry.

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## Conflict of Interest

The authors report there are no competing interests to declare.

## Use of Generative AI

ChatGPT was used in the preparation of this paper for translating Malay content into English, as well as for language refinement and grammar correction. No AI tools were used for generating research content, analysis or figures.

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