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Regular Article

Exploring Miao culture: The differential effect of traditional 2D and immersive 360° documentary formats on viewer learning

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ABSTRACT

This study explores the comparative effects of traditional 2D and immersive 360° documentary formats on educational outcomes and knowledge retention broadly on ethnic minority culture, represented by the Miao culture, one of the most representative in the country. As digital platforms dominate cultural education, understanding how advancements in storytelling, particularly immersive media, impact learning is crucial. Using visual materials capturing Miao villages, folk dances, and crafts as a case study, the study produced documentaries in both formats. Eighty-four participants engaged with these documentaries, providing data on knowledge retention and viewer engagement. Participants viewing the 360° format reported higher self-assessed content recall compared to those viewing 2D documentaries. However, this perceived enhancement did not align with actual performance in quizzes, indicating a significant difference between perceived and actual knowledge retention. Findings suggest that while 360° documentaries may enhance viewer engagement in cultural contexts, they do not necessarily improve memory retention over traditional 2D formats. The findings challenge prevailing assumptions about the educational advantage of immersive 360° technology and emphasise the importance of a critical re-evaluation of these technological innovations in the context of digital heritage education.

1. Introduction

Since the late 20th century, digital technologies have transformed museums, shifting from traditional curatorial practices to embracing advanced technologies. The evolution has introduced innovative engagement and educational strategies, such as multimedia guides and interactive exhibits, fostering a visitor-centric approach (Dierking & Falk, 1998; Hein, 2000). Recent studies have highlighted the potential of immersive technologies in education, indicating effectiveness in promoting engagement and motivation among learners (Makransky & Petersen, 2021; Mayer, Omdahl, & Makransky, 2019). This study aims to explore how these principles can be applied to cultural education effectively. As noted by Ch'ng, Cai, Leow, and Zhang (2019), this evolution has sparked a discussion on the interplay between digital technologies, museums' interpretative strategies, and visitors' experiences. Immersive technologies like 360° technology, Augmented Reality (AR), and Virtual Reality (VR) have become increasingly accessible, enhancing visitor engagement and understanding of cultural contexts by providing immersive experiences that offer unique and encompassing perspectives of cultural artefacts and narratives (Wiryawan & Nuraisyah, 2023; Škola et al., 2020). This marks a shift towards interactive and engaging cultural representation, deepening visitors' understanding of cultural narratives.

In China, museums have increasingly used digital media to contextualise ethnic minority exhibitions, offering visitors a deeper insight into the histories, performances, and craftsmanship of these communities. However, traditional 2D presentations have been critiqued for sometimes flattening the viewers experience and detracting from the cultural authenticity, thereby limiting immersive engagement (Sun & Ch'ng, 2024). This observation has sparked interest in exploring more immersive representational formats that could more effectively capture the essence of ethnic artefacts and their original contexts.

In response to this need, this study broadly investigates the effect of traditional 2D and immersive 360° documentary formats on viewer engagement and knowledge retention across digital exhibitions of ethnic cultural heritage. This paper, while part of a larger study, specifically

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concentrates on the aspect of knowledge retention. We hypothesise that immersive formats, while enhancing engagement and authenticity, might also differ in their effectiveness in facilitating knowledge retention when compared to traditional 2D presentations. This is crucial as museums and cultural sites increasingly use digital technologies to communicate ethnic minority cultures, potentially enhancing visitor experiences with more contextually rich media.

Furthermore, the study examines the potential influence of prior visits to cultural communities—considered a form of pre-training—on the effectiveness of these presentation methods. Our findings aim to contribute to the ongoing discussions about the role of immersive technologies in cultural education. By refining digital curatorial practices, this research seeks to bridge gaps between cultural heritage and digital technology, ensuring that the technological enhancements serve to enrich cultural narratives rather than overshadow them.

2. Literature review

The emergence of extended reality (XR), such as 360° technology, augmented reality (AR), virtual reality (VR), and other mixed reality technologies, has significantly shaped how cultural heritage is communicated, experienced and interpreted in recent decades. XR technologies offer immersive environments that enhance visitor engagement by enabling interactive explorations that deepen users' connection with cultural narratives. This adoption across museums globally represents a shift towards more dynamic and participatory forms of cultural representation (He, Wu, & Li, 2018; Ferdani, Fanini, Piccioli, Carboni, & Vigliarolo, 2020; Trunfio, Lucia, Campana, & Magnelli, 2022). This shift towards interactive and engaging cultural representation visitors' understanding of cultural narratives.

Central to the effectiveness of XR technologies in educational settings is the Cognitive Affective Model of Immersive Learning (CAMIL), which posits that the depth of immersion and interactivity significantly influences both cognitive and affective outcomes (Makransky & Petersen, 2021). The pre-training principle further supports the use of XR by suggesting that introducing learners to key concepts before engaging in complex XR tasks enhances learning effectiveness, particularly in immersive environments (Mayer & Pilegard, 2014; Mayer et al., 2019). The foundational knowledge can help reduce cognitive overload, allowing learners to engage more fully with the immersive content.

Reflecting on Belting's critique of the decontextualisation of African masks in colonial museums, a similar issue affects ethnic artefacts in Chinese museums. Belting argued that these masks are deprived of their inherent meaning once deracinated from their cultural and ritualistic context, becoming mere display objects rather than symbols of living tradition (Belting, 2017). He described that this creates an 'insurmountable cultural barrier' between the viewers and the artefacts' origins (Belting, 2017). Digital technologies have helped bridge the cultural gap by providing contextual information, thus enhancing the meaningful connection between visitors and artefacts, as illustrated in the Guizhou Provincial Museum (Sun & Ch'ng, 2024). Similarly, Loyola University Chicago's May Weber Ethnographic Study Collection not only provides an online platform, allowing global access to the collection's fragile ethnic textiles, but also features short videos demonstrating the processes of ethnic craftsmanship, enriching the visitor's appreciation of the artistry and cultural context of these textiles (Sun & Nichols, 2021).

Digital technologies in museums, while often informative, are increasingly complemented by interactive and experience-based technologies. Milk described 360° technology as an 'empathy machine,' capable of deeply engaging viewers in the experiences of others. This concept was exemplified by his project capturing the daily life of a Syrian girl in a Jordanian refugee camp with a 360° camera, significantly enhancing viewer empathy and connection (Milk, 2015). Such immersive experiences facilitate a deeper understanding and connection with the subject matter, making them a powerful tool for cultural representation. Selmanović et al. (2020) further demonstrated 360° videos' potential to enhance immersion and engagement, offering a first-person view of cultural practices like bridge diving in Mostar, Bosnia and Herzegovina, thus deepening the cultural learning experience.

However, the academic focus on the role of XR in enhancing museum experiences often neglects its effect on learning outcomes, focusing rather on the impression these digital technologies can create for visitors. While a systematic review by Chen, Duan, and Wang (2021) acknowledged the broad use of digital technologies in enhancing museum learning experiences, it fell short of specifically addressing the role of XR technologies, especially 360° technology. In this context, Mayer's Cognitive Theory of Multimedia Learning and Flavell's concept of metacognition emerge as relevant. Mayer's theory highlights the importance of leveraging multiple sensory channels in learning, suggesting that the format of multimedia presentations significantly affects learners' knowledge retention and outcomes (Mayer, 2014). Moreover, metacognition, focusing on individuals' awareness and regulation of their cognitive processes, provides profound insights into how learners monitor, evaluate, and adjust their approaches to absorbing new information (Flavell, 1979). These theoretical frameworks illustrate the cognitive processes underlying learning with 360° technology, yet the deliberate applications of Mayer's theory and metacognitive strategies specifically to 360° technology in museum settings have not been adequately explored. This gap suggests a promising avenue for future research aimed at better leveraging 360° technology to not only engage visitors but also to improve the learning experience.

In conclusion, while XR technologies have revolutionised museum practices and visitor experiences, enhancing engagement and bringing cultural narratives to life in unprecedented ways, their potential to enhance educational outcomes, especially in the context of ethnic minority exhibitions, remains largely unexplored. Further research should focus on refining immersive experiences with an educational emphasis, exploring how multimedia learning theories and metacognition can be applied to maximise the educational benefits of these extended technologies in museum settings.

3. Materials and methods

3.1. Materials

The primary materials for this study consisted of documentary footage collected from the Miao community in the less-touristy areas of Qiandongnan Miao and Dong Autonomous Prefecture. This location was selected due to its unique cultural significance within the broader landscape of ethnic minority communities in China. The Miao community, the largest ethnic minority in Guizhou, stands out for its distinct cultural identity, characterised by distinctive adornments and traditions that symbolise the rich diversity of ethnic minority cultures in Chinese museums (Varutti, 2014). This makes the Miao community an ideal subject for our research. By focusing on less-touristy areas, the study ensured authenticity and maintained the cultural integrity of the representations.

After editing, the documentaries, totalling 7 min and 5 s, depict Miao culture, from village life and traditional dances to the processes of traditional craftsmanship. They offer viewers an in-depth understanding of Miao traditions (see Table 1).

3.2. Methods

3.2.1. Design

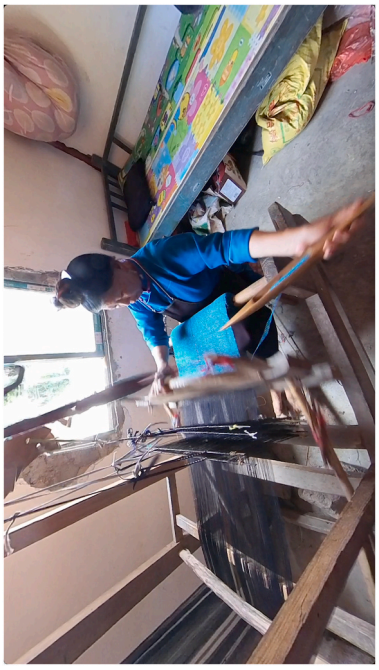
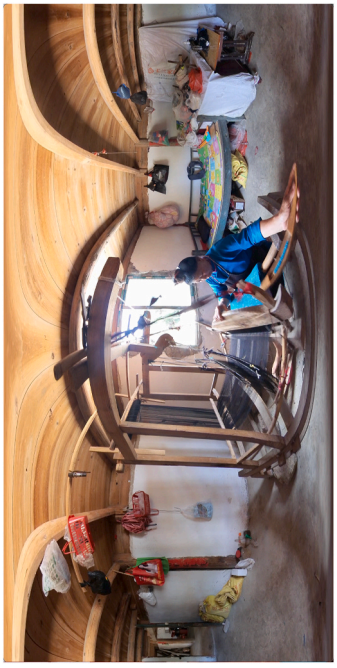
The comparative study investigates how traditional 2D and immersive 360° documentaries impact knowledge retention about Miao culture. It also considers the influence of prior visits to Miao communities, which serve as a form of pre-training and provide foundational knowledge.

Table 1
Documentaries Overview.

No	2D View	360° View Equirectangular Panorama	Description
1			This is the opening shot, showing the renowned Miao architectural form, a lounge bridge. (Handheld shooting)
2			The shot shows a scene of the Miao people performing the Lusheng Dance in a plaza. Men played the traditional musical instrument—Lusheng, while women, adorned in traditional costumes, danced rhythmically. (Tripod shooting)
3			The shot shows the first step of batik-making—wax application. The practitioners confidently and instinctively draw directly on the fabric using hot wax. (Tripod shooting)

(*continued on next page*)

Table 1 (*continued*)

No	2D View	360° View Equirectangular Panorama	Description
4			The shot captures an elderly Miao woman skillfully weaving on a traditional weaving loom. (Tripod shooting)

Source(s): Photos by Xiaolin Sun using Insta360 X3

The approach provides insights into the design and application of documentaries in cultural education, particularly in settings where audiences have diverse backgrounds and experiences.

3.2.2. *Materials preparation and equipment setup*

The documentary was filmed with the Insta360 X3 camera. Before filming, in-depth consultations with local Miao community members ensure authentic representation. The collaborative process also led to the decision to exclude the process of silver jewellery production, an integral aspect of Miao costume culture, due to its complexity.

After filming, Insta360 Studio was used for preliminary edits, automatically combining .lrv and .insv files, and Adobe Premiere Pro 2024, Adobe After Effects 2024, and Photoshop 2024 were used for advanced editing and visual enhancements, focusing on essential corrections like tripod and selfie stick shadow removal. Voiceovers were generated by WellSaid Labs' AI technology, with Fiona H.'s voice avatar providing clear and engaging narration. The documentaries were reviewed by several Miao people across different age groups to ensure their authenticity and cultural accuracy and were exported in two formats (2D and 360°) for the research.

The 2D documentary was displayed on a 55-inch MAXHUB TV, and the 360° documentary was viewed through Pico 4 VR headsets. Participants were instructed to use the VR equipment to navigate the documentaries comfortably. Fig. 1 illustrates engagement during the screenings.

3.2.3. *Participants*

The study combined stratified random sampling and snowball sampling. The target was 80 participants, balanced between two formats and whether they had visited Miao communities. Recruitment was initiated via WeChat, with snowball sampling later employed to ensure sufficient individuals who had visited Miao communities because the number of applicants with prior visits was lower than needed. Finally, from 138 applications, 94 participants (52 females, 42 males) aged 16–45 were selected based on their self-reported English proficiency to engage with the documentary content effectively.

3.2.4. *Procedure*

Before viewing, participants received an experimental information sheet and signed a consent form approved by the university's ethics board, which detailed the study's purpose, procedures, and rights. After signing these forms, they filled out a pre-viewing questionnaire to collect demographic information, assess pre-existing knowledge of Miao culture, and understand their viewing habits. Special attention was given to ensuring that all data was anonymised and securely stored to protect participant privacy. Once they completed the pre-viewing questionnaire, participants were assigned to watch either the 2D or 360° documentary, considering self-reported medical conditions such as a history of vertigo, claustrophobia, or discomfort with watching 360° or VR content. Participants were informed that they could withdraw from the experiment at any time without consequence. After the documentary screening, participants completed a post-viewing questionnaire. To ensure data integrity, the initial participant pool of 94 was carefully reviewed, and ten participants were excluded because of significantly shorter questionnaire completion time and inconsistencies in reported prior visits to Miao communities. The remaining participants were evenly distributed into two groups for the final analysis, 42 for each format group, with an equal number of participants who had visited Miao communities and those who had not.

3.2.5. *Measure*

The evaluation of the documentaries' impact on viewer knowledge retention employed a mixed-methods approach, incorporating both subjective self-assessment and objective quiz to provide a comprehensive analysis of educational outcomes.

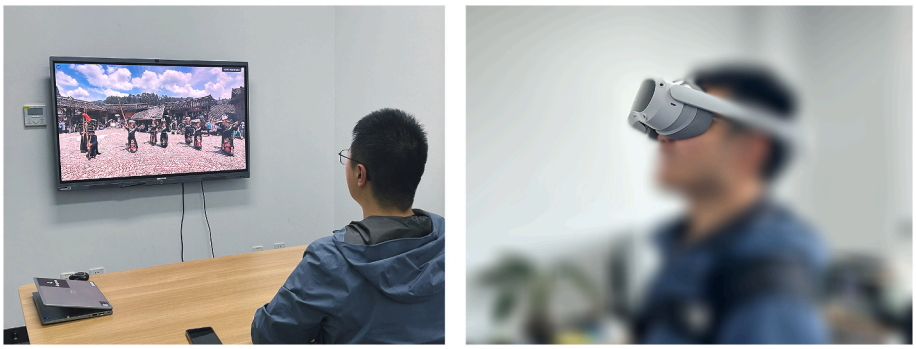


Fig. 1. Participants were engaged with the 2D documentary (left) and the 360° documentary (right). Source(s): Photos by Xiaolin Sun.

1. **Subjective Self-Assessment:** Participants were asked to rate their recall of documentary content on various cultural aspects, including the Miao's history, batik-making processes, the significance of folk dance, and embroidery patterns, immediately after viewing. This was done using seven-point Likert scales ranging from *strongly disagree* to *strongly agree.* The statements included "I can recall the history of the Miao after watching the documentary" and "I can recall the process of making Miao's batik after watching the documentary." These subjective measures offered insights into the viewers' perceived learning.
2. **Objective Quiz:** To objectively assess actual knowledge retention, participants completed a series of ten single-choice questions derived directly from the documentary content (mainly from the documentary's voiceover). These questions were designed to measure the participants' recall of specific details, providing a concrete measure of learning outcomes.

Table 2 below lists all the quiz questions used in the study, along with the multiple-choice options provided to the participants.

Data collected from the self-assessment and quiz were numerically coded and analysed using statistical software. This analysis helped in assessing how different formats (2D vs. 360°) affected participants' knowledge retention, considering variables such as prior visitation to Miao communities.

Table 2
Quiz questions for assessing knowledge retention.

No	Quiz Question	Options (bold one is a correct answer)
1	Which musical instrument is iconic and traditionally associated with Miao's culture?	A. Guzheng (Chinese zither) B. **Lusheng (a reed pipe wind instrument)** C. Erhu (a two-stringed bowed instrument) D. Pipa (a plucked string instrument)
2	What is the primary significance of Miao's traditional dances?	A. **Celebrating good harvest** B. Fashion trends setting C. Rituals for good luck D. Warrior training
3	How many primary steps are involved in the traditional Miao batik-making process as depicted in the documentary?	A. 3 steps B. 4 steps C. **5 steps** D. 7 steps
4	How is the design applied to the fabric in the batik-making process?	A. By painting directly with dyes B. By using a stencil and spray C. **By drawing with hot wax** D. By screen printing
5	In the Miao batik-making process, what happens after the wax is applied?	A. The fabric is soaked in cold water B. **The fabric is dyed** C. The fabric is left in the sun D. The fabric is ironed
6	How is the wax removed from the fabric after dyeing in Miao batik?	A. Scraping off with a knife B. **Washing with hot water** C. Ironing between sheets of paper D. Applying vinegar
7	In Miao batik-making, why are some fabrics dyed multiple times?	A. **To achieve deeper shades of color** B. To fix mistakes in the pattern C. To make the fabric softer D. To create a layered pattern
8	Miao embroidery techniques have been passed down through?	A. Professional schools B. Written documents and manuals C. **Generations, usually from mother to daughter** D. Television programs
9	Which of the following is NOT a traditional pattern of Miao embroidery?	A. Flowers and plants B. Historical battles C. Animals D. **Modern technology**
10	Miao embroidery often serves as a form of?	A. Currency in the local market B. **Identify different groups** C. Display in museums and art galleries D. Gifts during political events

4. Result

4.1. Descriptive data

While the post-viewing questionnaire explored various dimensions, this paper narrows its scope to focus on the effect of documentary formats on the retention of cultural knowledge. Table 3 presents descriptive data that highlight differences in how effectively content was retained and understood, key metrics for assessing the educational impact of the documentaries. Research indicates that pre-training can significantly enhance learning outcomes in immersive environments by providing essential foundational knowledge, thus reducing cognitive overload during the main learning task (Mayer et al., 2019). In alignment with this, prior visits to the Miao community in our study acted as effective pre-training. The results reveal that participants who viewed the 360° documentary format were not only more engaged but also retained significantly more information about Miao culture compared to those who viewed the 2D version. This suggests that immersive technologies can enhance knowledge retention by providing a more engaging and interactive viewing experience.

4.2. Data findings and visualisation

In the analysis, we evaluated knowledge retention in 84 participants (45 females and 39 males), aged between 16 and 45, using traditional 2D

Table 3
Descriptive data.

Combined Variable	Variables	2D		360°	
		$\bar{x}$	σ	$\bar{x}$	σ
Content Retention	I can recall the history of the Miao.	4.214	1.601	4.548	1.383
	I can recall the significance of Miao's folk dance.	5.262	1.191	5.643	1.122
	I can recall the process of making Miao's batik.	5.833	1.034	6.310	0.749
	I can recall the various patterns commonly used in Miao embroidery.	5.238	1.694	5.405	1.083
Understanding	How confident are you in your understanding of the main cultural practices of the Miao people as presented in the documentary?	4.452	1.214	4.643	1.265
	The documentary helped me understand how the Miao's textiles and costumes are more than just an art form but a representation of their history and identity.	5.381	1.306	5.548	1.041

(Note: Responses were collected using a 1-to-7 Likert scale where 1 represents 'strongly disagree' and 7 represents 'strongly agree').

and immersive 360° documentary formats. Each format was viewed by 42 individuals, with groups further balanced by prior exposure to Miao culture. This structured approach allowed for a detailed examination of how different documentary formats influenced viewers' understanding of Miao culture.

An assessment of participants' familiarity with 360° technology, using a Likert scale from 1 (very unfamiliar) to 7 (very familiar), grouped participants into three groups based on their scores. A majority, 65% (n = 55), reported low familiarity, rating their experience as low (scores of 1–3). In contrast, fewer than 20% (n = 15) reported high familiarity (scores of 5–7), and 17% (n = 14) selected a neutral stance (score of 4). A Kruskal-Wallis test revealed significant differences in familiarity levels among these groups ($H = 62$, $p < 0.05$), indicating significant differences in participants' exposure to and understanding of this technology. These results underscore the need for designed educational strategies to effectively address the diverse levels of familiarity and optimise the integration of 360° technology in learning environments.

After assessing participants' familiarity with 360° technology, Fig. 2 illustrates their cultural learning preferences. The data shows that participants who had not visited Miao communities clearly preferred visual sources over reading, with visual methods receiving a median rating of 6. Travel was particularly valued for cultural learning, as evidenced by the dense clustering of high ratings for 'Travel > Visual.' Participants with prior visitation experiences recognised travel's benefits, consistently rating it a median of 6 with a narrower interquartile range of 2. This suggests that travel provides a uniquely enriching experience that many find essential for understanding culture deeply. The data highlight that travel is considered the most enriching approach to cultural learning, particularly by those with firsthand travel experiences.

The boxplots in Fig. 3 illustrate a clear trend in participants' self-assessed familiarity with Miao culture. Participants who had visited Miao communities reported significantly higher familiarity scores across all surveyed categories, as confirmed by statistically significant results from the Mann-Whitney U test. For 'History of Miao' ($U = 1284$, $p < 0.05$), 'Folk Dance' ($U = 1343$, $p < 0.05$), 'Batik' ($U = 1256$, $p < 0.05$), and 'Weaving and Embroidery' ($U = 1257.5$, $p < 0.05$), the results show significant differences in familiarity between those who visited and those who did not, highlighting the enriching impact of direct experience on enhancing cultural understanding.

Variability in scores among those who had visited suggests that experiences within Miao communities are highly personalised, reflecting the diverse cultural emphases within the community and the varying interests of the participants. In contrast, participants who had not visited Miao communities showed a consensus in their lack of familiarity, attributed to their limited direct exposure. Notably, the higher median value of 23.5 for 'Folk Dance', compared to consistent median values around 20 for other categories among those who visited, highlights its significance as a central cultural element, frequently used in promotional materials because of its appealing visual effect.

These insights emphasise the necessity for digital innovations in cultural education that accommodate and reflect the diversity of cultural presentations and align with visitors' interests, fostering a more comprehensive and engaging cultural understanding.

Fig. 4 presents a comparison of the contribution of narrative and visual elements to participants' understanding of the content across the 2D and 360° documentary formats. Visual elements were consistently rated higher, with median scores of 60, compared to narrative elements with scores of 40. This suggests that visuals were perceived as more consistently impactful in the 360° format. The Wilcoxon signed-rank test was used to validate these observations statistically. For the 2D format, results indicated a statistically significant difference in the impact of visual versus narrative elements ($W = 192$, $p < 0.05$). Similarly, for the 360° format, the results were also significant ($W = 22$, $p < 0.05$). These findings confirm that visual elements contribute more significantly to understanding than narrative elements in both formats.

Our study employed two distinct methods to evaluate knowledge retention, as detailed in section *3.2.5 Measure*.

The first method involved participants providing subjective ratings of their recall of four cultural aspects, including the history of Miao, batik-making processes, the significance of folk dance, and embroidery patterns. These aspects were rated using seven-point Likert scales, the results of which are illustrated in Fig. 5. Using the Mann-Whitney U test, we compared recall rates among participants who had not previously visited Miao communities. Those who experienced the 360° format reported statistically significant higher recall rates for the history of Miao ($U = 135.5$, $p < 0.05$) and the batik-making processes ($U = 118$, $p < 0.05$) compared to those who viewed the 2D format. However, no significant differences were found in the significance of folk dance ($U = 158$, $p = 0.108$) or embroidery patterns ($U = 188.5$, $p = 0.411$). Descriptive statistics support these findings, with mean recall scores for

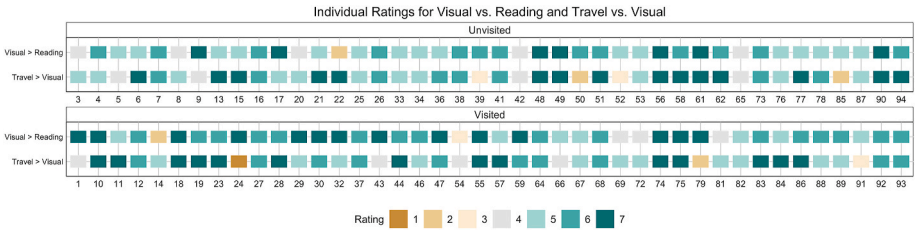


Fig. 2. Participants' preferences for cultural understanding methods. Source(s): Figure created by Xiaolin Sun using R studio.

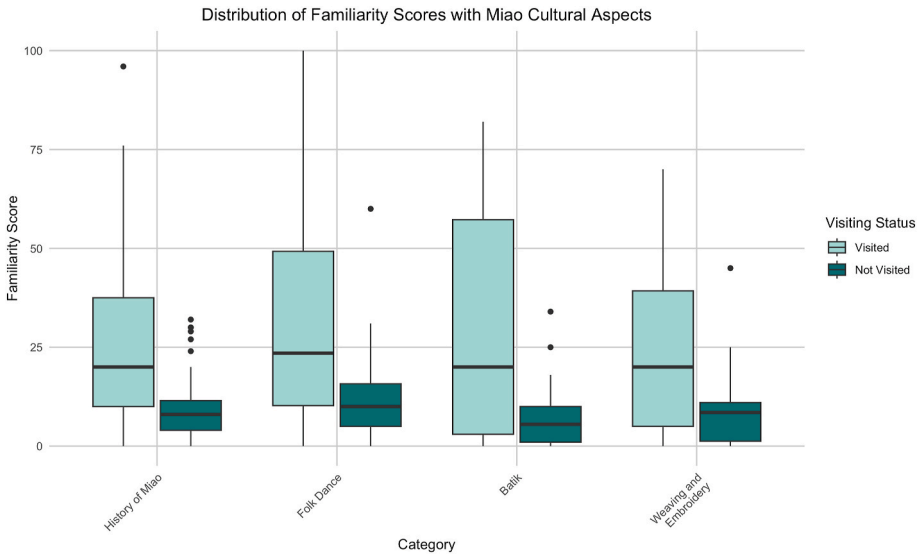


Fig. 3. Boxplots of familiarity scores with Miao cultural aspects. Source(s): Figure created by Xiaolin Sun using R studio.

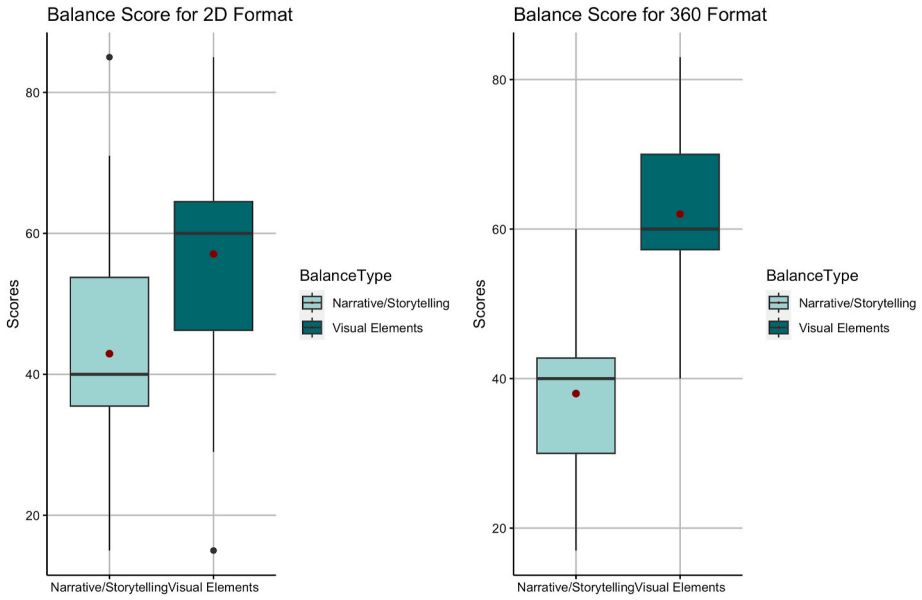


Fig. 4. Balance scores for visual and narrative elements in understanding Miao culture by documentary formats. Source(s): Figure created by Xiaolin Sun using R studio.

history at 4.71 in the 360° format versus 3.86 in the 2D format, and for batik-making processes at 6.19 compared to 5.38. These findings highlight the effectiveness of the 360° format in facilitating cultural learning, particularly for individuals without direct exposure to Miao culture.

In contrast, among participants who had visited Miao communities, the recall rates between the two formats did not show statistically significant differences for any of the cultural aspects, as shown by the Mann-Whitney *U* test: 'the history of Miao' ($U = 231$, $p = 0.797$), 'the significance of folk dance' ($U = 209.5$, $p = 0.782$), 'batik-making processes' ($U = 205.5$, $p = 0.685$), and 'embroidery patterns' ($U = 249$, $p = 0.469$). This suggests that personal experiences might have maximised their recall capabilities, diminishing the differential effect of the documentary formats. This pattern indicates that prior personal interaction with the culture may mitigate the impact of different educational formats on recall ability.

The second method revealed a distinct differential effect on knowledge retention, as illustrated in Fig. 6. Participants who had visited Miao communities achieved an average accuracy of 80.48% for the 2D format, which was significantly higher than the 69.05% accuracy for those experiencing the 360° format. The Mann-Whitney *U* test confirmed this significant difference ($U = 306.5$, $p < 0.05$). Similarly, participants who had not visited Miao communities echoed this pattern, achieving an average accuracy of 79.52% for the 2D format and an average accuracy of 63.33% for the 360° format, with a *U* value of 346.5 ($p < 0.05$). These findings indicate a clear advantage of the 2D format in facilitating knowledge retention.

Our analysis also explored that prior visitation to Miao communities did not significantly influence the quiz results within each format. The Mann-Whitney *U* test for the 2D format resulted in a *U* value of 215.5 ($p = 0.907$), and for the 360° format ($U = 259$, $p = 0.33$). This suggests that the effectiveness of the documentary format in improving knowledge retention is consistent, regardless of participants' previous exposure to Miao communities.

Furthermore, a Kruskal-Wallis test was conducted to explore the

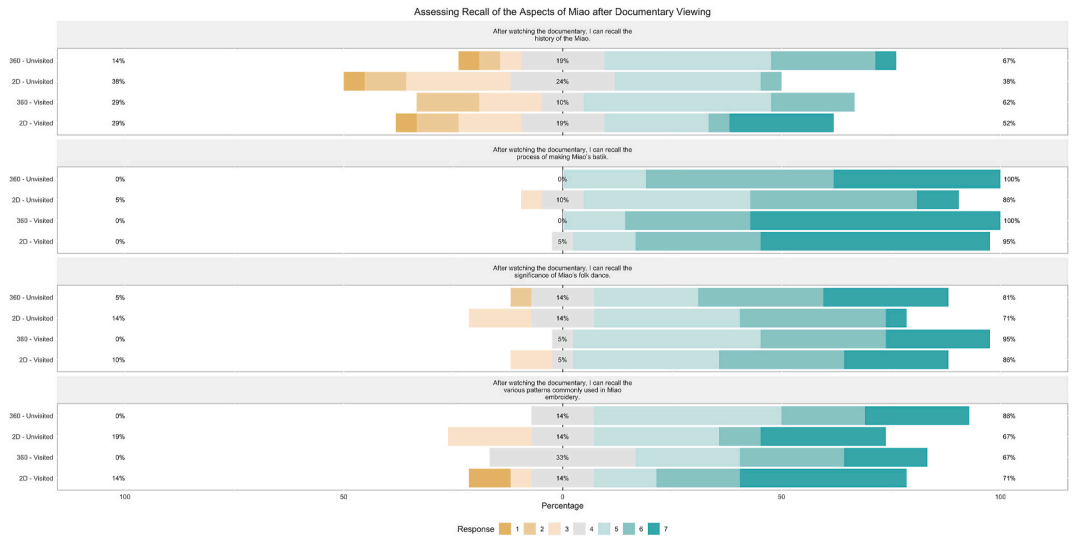


Fig. 5. Participants' self-assessment of four cultural aspects after documentary viewing. Source(s): Figure created by Xiaolin Sun using R studio.

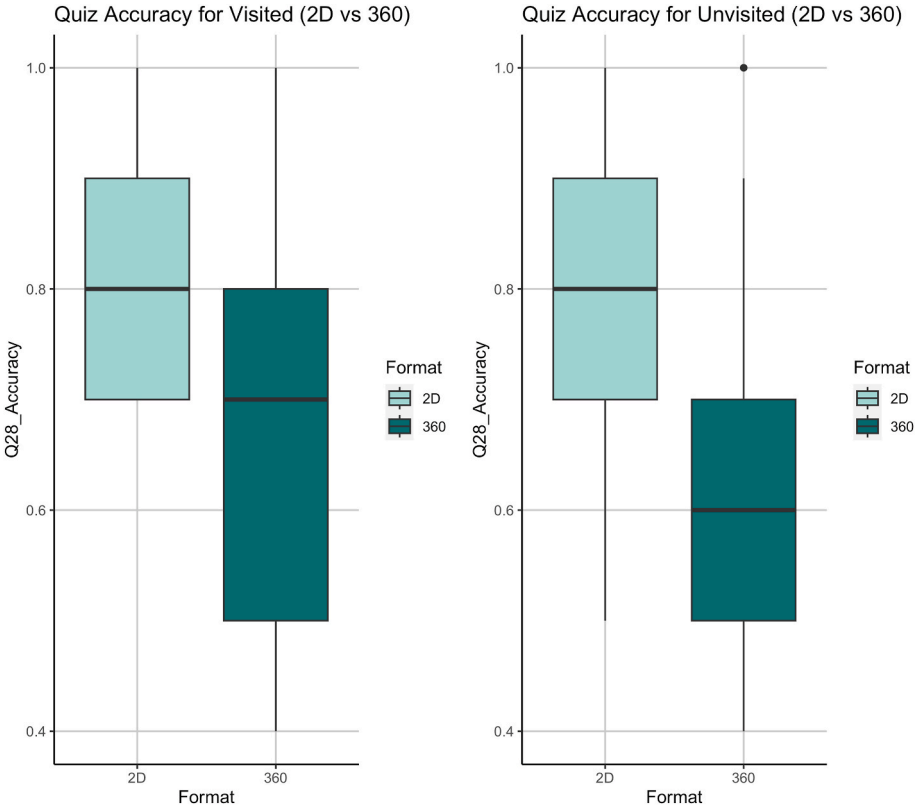


Fig. 6. Quiz accuracy for participants by documentary format (2D vs 360°). Source(s): Figure created by Xiaolin Sun using R studio.

interaction between the format and visiting status, revealing a significant effect ($H = 16.82$, $p < 0.05$). This indicates that the combined factors of documentary format and prior visitation significantly impact knowledge retention, suggesting a complex interplay between these variables.

The results emphasise the educational efficacy of the 2D format, which appears to be more conducive to knowledge retention than the 360° format, regardless of prior visitation to Miao communities. While 2D formats offer better learning retention, 360° formats remain valuable for experiential learning. This study underscores the importance of selecting appropriate documentary formats in cultural education, designed to the audience's background and educational goals.

5. Discussion

Our investigation into Miao culture through traditional 2D and immersive 360° documentaries illuminates a comprehensive assessment of how visual storytelling impacts audience engagement and knowledge retention. This section evaluates the efficacy of visual elements in cultural representation and education, compares the effects of 2D and 360° formats on the retention of memory, and explores the differences between perceived and actual knowledge retention. By contextualising our

work within broader digital media learning and digital cultural heritage scholarship, the study extends the application of our findings in digital cultural heritage preservation and proposes future research directions.

Visual storytelling serves as a bridge, connecting learners to the complexities of cultural narratives and significantly enhancing their comprehension and retention of cultural knowledge. In our exploration of Miao culture, we emphasise the benefits of media formats in capturing attention and surmounting language barriers, thereby making cultural content more accessible and engaging for audiences.

The early adoption of visual elements in cultural representation can be traced back to the late 19th and early 20th centuries through Haddon's pioneering use of film in the Torres Strait Islands expedition (Griffiths, 2002; Long & Laughren, 1993). This period marked a shift toward acknowledging the limitations of text-only ethnographies and the indispensable value of visual documentation. Scholars like MacDougall (1999) and Edwards (2002) highlighted the incomplete insights offered by traditional fieldwork without the inclusion of visual media. Similarly, Mead (1995) recognised the contributions of photography to anthropological research. Psychological studies indicated that visual information greatly aids our cognitive organisation more effectively than text alone (Joe, Kovesdi, Mack, & Miyake, 2019).

Kiss and Weninger's research further supports the educational value of visuals, demonstrating that images can bridge cross-cultural understanding by analysing diverse cultural responses to a visual depiction of the Indian Holi festival in an EFL classroom (Kiss & Weninger, 2017). This finding resonates with our study's results, where participants clearly preferred visual media over text-based methods in cultural learning, as evidenced in the pre-viewing questionnaire. Further, the post-viewing questionnaire showed that visual elements play a more crucial role than narrative storytelling in facilitating cultural understanding. This preference was consistently observed across both 2D and 360° documentary formats, thereby broadening the academic discourse on the efficacy of visual learning and highlighting the universal appeal of visual aids in enriching cross-cultural engagement.

Moreover, immersive 360° technology offers a promising alternative for those who cannot physically visit these cultural sites. By simulating travel's sensory and spatial aspects, 360° videos can provide a virtual and impactful exploration of cultural settings. This adaptation not only makes cultural education more accessible but also aligns with the need to accommodate diverse learner preferences and limitations. Such technological solutions could crucially bridge the gap for individuals who prioritise visual and experiential learning but lack the means to engage directly with distant cultural sites. Notably, the immersive visual elements in the 360° documentary format were more important for deepening viewers' cultural understanding, suggesting a potential for innovative technologies to shape future educational endeavours.

The demographics of the participants are characterised as digital natives, and this lends additional insight into our findings. Digital natives grew up in digital and media-rich environments. Intuitively, there is a preference for acquiring information through digital media, which are visual, and from moving images, i.e., videos, animation, etc., rather than text-based formats (Prensky, 2001; Abdul Aziz, Harun, Baharom, & Ramlie, 2019). This tendency is echoed in Ch'ng, Li, Cai and Leow's observations of a similar preference for visual formats in VR applications for cultural heritage education (Ch'ng, Li, Cai, & Leow, 2020). The preference among this demographic for engaging with technology-driven content delivery suggests that adopting innovative visual formats like 360° documentaries could enhance cultural engagement and understanding. This strategic shift towards visual-centric education marks an essential step in enriching educational experiences and aligns with the technological fluency and preferences of today's learners.

Our comparison of 2D and 360° documentary formats on knowledge retention draws on Mayer's Cognitive Theory of Multimedia Learning. This theory highlights the importance of optimising multimedia presentations using auditory and visual channels, which is particularly relevant given learners' limited capabilities in each channel (Mayer, 2014). Understanding the higher knowledge retention associated with the 2D format suggests that its structured presentation aligns well with learners' cognitive limitations, facilitating more effective educational outcomes.

Mayer (2014) emphasised active processing, where meaningful learning emerges from cognitive activities such as selecting, organising, and integrating information. The structured and straightforward nature of 2D documentaries supports these cognitive processes more efficiently than the immersive and engaging 360° format. The latter might introduce irrelevant cognitive load, detracting from learners' focus and absorption of critical content—a challenge Mayer highlights the importance of addressing by structuring content to facilitate cognitive processing (Mayer, 2014). The immersive, continuous and unsegmented information flow in the 360° format could exceed learners' cognitive capacity, interfering with effective knowledge retention, which aligns with Mayer's principles.

The influence of format familiarity on cognitive efficiency is significant, as revealed by our study's findings of participants' general unfamiliarity with 360° technology. More familiar 2D formats support easier information processing and retention, highlighting how familiarity enhances cognitive processing efficiency. Accordingly, the 2D format's effectiveness for knowledge retention among our participants becomes evident. However, as exposure to immersive technologies increases, learners are expected to improve in processing and engaging with 360° formats. This shift indicates a growing adaptability to immersive learning environments, suggesting a future where such technologies become integrated into educational strategies.

Furthermore, the findings highlight the enriching impact of direct experience on cultural understanding, aligning with the pre-training principle where prior exposure to foundational knowledge can enhance learning outcomes (Mayer & Pilegard, 2014). The observed variability in scores among those who had visited suggests that experiences within Miao communities are personalised, indicating that such pre-training can reduce cognitive load during subsequent immersive experiences (Mayer et al., 2019). This study extends existing literature by demonstrating the potential of VR to enhance engagement and motivation, as well as facilitate cultural education through immersive experiences. However, it is crucial to address cognitive load challenges associated with immersive VR, which can be mitigated by incorporating pre-training strategies to familiarise learners with key concepts beforehand (Makransky & Petersen, 2021; Mayer & Pilegard, 2014).

Therefore, our study suggests instructional designs must consider learners' cognitive capacities to promote effective educational engagement. In addition, educators and content creators are encouraged to progressively introduce immersive content, preparing learners for a future where these formats play a central role in educational contexts.

The difference between perceived and actual knowledge retention in participants experiencing the 360° documentary, where lower quiz accuracy contrasted with paradoxically higher self-assessment recall rates, reveals the complexity of metacognitive judgements within immersive learning environments. This observation, grounded in the concept of metacognition as introduced by Flavell, which refers to the awareness and regulation of one's cognitive processes, becomes crucial in understanding learners' assessments of their learning experiences, especially with novel technologies (Flavell, 1979). Our investigation aligns with Dunlosky and Rawson's insights into metacognitive judgements to explore the observed gap in knowledge retention within immersive 360° content contexts (Dunlosky & Rawson, 2012). Building on this theoretical framework, we explore three hypotheses: the illusion of knowledge, the seductive details effect, and the Dunning-Kruger effect, each revealing potential cognitive biases that influence learners' self-perception and actual understanding in immersive educational contexts.

The illusion of knowledge, a bias where learners overestimate their understanding or memory of information, can lead to a perceived

understanding being better than actual knowledge. An illustrative example of this phenomenon comes from Hall, Ariss, and Todorov's study on predictions of NBA game outcomes. The research found that participants provided with additional information, such as team names, not only predicted outcomes with lower accuracy but also exhibited higher confidence in their predictions (Hall, Ariss, & Todorov, 2007). Similarly, in our study, the inclusion of extra cultural content in the 360° documentary might lead to this illusion among participants. Immersed in the rich cultural narrative and visuals of the Miao community, participants reported higher recall rates despite lower quiz performance. This paradox suggests that engaging excessive details in the immersive format can make individuals overconfident in their judgments despite a decrease in actual retention.

The seductive details effect suggests that interesting but irrelevant information within educational content can distract from main learning objectives, negatively impacting knowledge retention and understanding. Harp and Mayer demonstrated this effect by comparing students' recall and problem-solving abilities after studying passages with and without seductive and irrelevant details. Their findings showed that the inclusion of such details negatively impacted learning outcomes (Harp & Mayer, 1998). Reflecting this in our context, the 360° documentary's visually rich environment, filled with captivating but non-central elements like the daily utensils and other surroundings, may divert attention from the educational core of the content. This diversion emphasises the challenge of balancing immersive experiences with focused learning objectives in educational content design.

Additionally, the Dunning-Kruger effect, a cognitive bias where individuals with limited knowledge overestimate their competence, illustrates the overconfidence observed in self-assessments. Kruger and Dunning's work on inadequate metacognitive awareness leads to exaggerated self-evaluations (Kruger & Dunning, 1999), which resonates with our findings. In our study, this effect is caused by participants' unfamiliarity with the immersive format and Miao culture, decreasing their ability for accurate self-evaluation and resulting in overconfident assessments of their understanding.

Furthermore, the novelty of the 360° documentary format represents an important factor to consider. The novelty effect suggests that the newness of a technology influences user engagement and subjective perceptions of learning. Participants' heightened engagement with the innovative 360° technology might make them overestimate their understanding and learning outcomes. This phenomenon aligns with findings from Clark and Mayer, who suggest that novel educational tools can sometimes result in heightened perceived understanding due to their engaging nature without corresponding increases in actual learning (Clark & Mayer, 2016). Therefore, the challenge lies in designing such immersive technologies in a way that not only captures the initial attention of learners but also promotes deep cognitive processing. This requires instructional designs that go beyond the novelty to support sustained and meaningful engagement, ensuring that perceived comprehension aligns more closely with actual learning achievements.

These insights emphasise the necessity of educational strategies that enhance metacognitive awareness, aiming to minimise discrepancies between perceived and actual knowledge in culture. This approach is crucial, particularly in the use of immersive technologies for cultural education, where the impact of novelty and cognitive biases must be carefully managed. Reflecting on Belting's critique of the decontextualisation of African masks, which lose their inherent meaning and become mere objects of display when removed from their cultural and ritualistic context, and the challenges of presenting intangible cultural heritage, we recognise the need to not only engage but also deeply educate. Future research should evaluate the impact of immersive technologies on the retention of cultural knowledge and investigate the contribution of interactive elements to learning outcomes.

In addition, educators should critically evaluate immersive technologies. It is crucial to assess whether these technologies align with educational goals, enhance engagement, ensure accessibility, and offer cost-effectiveness. Such evaluations are essential not only for effective teaching and learning but also for the creation of digital tools that preserve and share intangible cultural heritage. By critically appraising these technologies, educators can ensure they are both impactful and sustainable, making cultural heritage accessible and engaging for future generations.

While our study offers valuable insights into immersive technologies in cultural education, it has limitations. The use of snowball sampling for participant recruitment, targeting those familiar with Miao communities, resulted in a younger demographic. This raises concerns about the generalisability of our findings across different age groups and backgrounds. Yet, we believe that the younger demographics would be the target audience for adopting technologies that would benefit from the transfer of cultural knowledge in museums. Additionally, our focus on immediate learning outcomes does not account for long-term knowledge retention. Future studies should aim for a more diverse participant pool and include long-term follow-up studies to measure the lasting effects of immersive educational experiences on a broader demographic sampling over time.

6. Conclusions

This paper explores the effects of traditional 2D and immersive 360° documentaries on knowledge retention concerning ethnic minority cultures, with a specific case study on Miao culture. While 360° formats provide immersive experiences, they do not necessarily enhance educational outcomes when compared to traditional 2D formats. This finding challenges prevailing assumptions about the educational advantages of immersive technologies in cultural heritage learning. Our research contributes to discussions on digital technologies' learning and cognitive engagement, highlighting the need for further exploration into how these extended reality technologies can be optimally used to enhance understanding of diverse cultures. The study suggests that educators and content creators critically evaluate the application of such technologies in education to ensure they contribute effectively to learning outcomes.

This study lays the groundwork for future research and instructional practices, advocating for the thoughtful integration of immersive technologies to deepen learners' engagement with cultural diversity within an educational framework. By integrating these technologies thoughtfully, we can enhance the educational impact and foster a deeper connection with a variety of cultural narratives.

Ethical statement

This research involved human participants and adhered to the principles outlined in the Declaration of Helsinki. Ethical approval for the study was obtained from the University of Nottingham Ningbo China Ethical Committee (the approved ethical document is attached for reference). Prior to participation, all participants were fully informed about the nature of the research, and written informed consent was obtained from each participant (the blank information sheet and consent form are attached for reference).

CRediT authorship contribution statement

Xiaolin Sun: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eugene Ch'ng:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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