



Including Cultural Context Improves Communication Outcomes for Quaternary Geoheritage: Evidence from Southeast Arabia

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15 **Abstract.** Effective science communication plays a crucial role in enhancing public understanding of Quaternary science. One potential strategy for advancing public engagement involves highlighting the interconnectedness of Quaternary sites, archaeology, and human culture. Despite the recent increased focus on science communication within the geosciences, the significance and effectiveness of emphasising such geocultural connections in communicating about Quaternary geoheritage sites have rarely been explored in experimental settings.

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This study investigates the efficacy of educational videos in communicating the significance of Quaternary geoheritage sites in southeast Arabia. Specifically, it examines the impact of including geocultural context information. An online experiment was conducted to evaluate the effects of videos produced with input from academics, museum professionals, and heritage administrators from the region. The study compares the impact of two different 9-minute videos—one emphasising the geocultural context, and the other focusing solely on Quaternary science—on participants' knowledge, interest, and perception of Quaternary geoheritage sites.

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Both videos were found to be effective overall in enhancing participants' self-reported knowledge of Quaternary geoheritage sites and increasing their overall interest. However, the inclusion of geocultural information resulted in improved long-term retention of information and heightened levels of interest, particularly among respondents without a specialist background in this field. Moreover, although the geocultural video was less effective as an immediate teaching tool compared to the Quaternary science-focused video, participants exposed to it reported better memory retention in the 3-months-after survey and demonstrated a stronger sense of the need to protect Quaternary geoheritage sites.

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Although the participant profile is limited to highly educated, relatively young adults with pro-nature attitudes, this study advances our understanding of the role of geocultural connections in communicating the importance of Quaternary science and raising awareness of Quaternary geoheritage. By demonstrating the benefits of incorporating information on cultural relevance into communication strategies, the study illustrates how Quaternary scientists and geoheritage practitioners can enhance audience engagement, deepen understanding, and inspire lasting changes in attitudes. These positive findings underscore the necessity for future research to explore the applicability of this concept in various social, cultural, and/or geographical settings.

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1 Introduction

Quaternary science holds significant relevance for society, with implications for climate change, sea level oscillations, coastal erosion, geohazards, historical biodiversity, and human evolution (Elias, 2007).

50 Furthermore, Quaternary processes have shaped numerous distinctive landscapes, some of which have been protected internationally. According to Boylan (2008), 17% of all World Heritage Sites characterised by geological features predominantly represent Quaternary features, including karstic landscapes (e.g. Plitvice, Croatia), deserts (Lut Desert, Iran), or volcanoes (Hawaii Volcanoes National Park, USA), despite this period only represents 0.057% of Earth's history. However, many geological heritage sites, or geoheritage sites, have
55 been protected (Chylińska, 2019) and visited (Štrba, 2019) for their aesthetic appeal rather than their scientific significance or appreciation, with Quaternary sites being no exception.

In both the World Heritage List (Boylan, 2008) and the Global Geopark Network (Brilha, 2018), Quaternary sites predominantly feature glacial, karstic, or volcanic formations, aligning the classic definition of natural
60 beauty (Churchward et al., 2013; Mitchell, 2013). Consequently, the communication and promotion of geoheritage sites, particularly concerning their scientific and societal importance, have emerged as crucial agendas (Gordon et al., 2018; Stewart & Nield, 2013).

Recognising the cultural significance of Quaternary sites presents a potential avenue to enhance their
65 appreciation among the general public. This concept, known as geocultural heritage (Kubalíková et al., 2020; Reynard & Giusti, 2018; Sayama et al., 2022), offers alternative pathways for non-experts to connect with these sites. Various studies have explored how specific sites embody interdisciplinary heritage values (Coratza et al., 2016; Gravis et al., 2017; Kazancı & Lopes, 2022; Mariani & Melis, 2022). However, the practical efficacy of this concept in interpreting and promoting Quaternary geoheritage sites has received limited attention,
70 particularly in terms of input from the relevant publics. By using educational documentary-style videos to introduce Quaternary geoheritage sites to the public in Southeast Arabia (i.e. the UAE and Oman), this study aims to provide data to help advance effective science communication of Quaternary geoheritage and evaluate the utility of the geocultural concept in this process.

75 1.1 Quaternary Geoheritage and its cultural dimension

Quaternary geoheritage sites encompass all geological/geomorphological sites whose primary heritage values originate in the Quaternary period (Sayama, 2024). This concept represents a broader interpretation of geomorphosites (sensu Reynard et al., 2009), which confines its definition to sites with aesthetic characteristics.
80 In general, Quaternary geoheritage sites demonstrate three main characteristics (Reynard, 2009; Sayama, 2024). Firstly, Quaternary geoheritage sites are dynamic, as they are strongly influenced by ongoing earth surface processes. These sites offer opportunities for observing current earth dynamics and are relatively susceptible to changes through weathering and other natural processes. Consequently, Quaternary geoheritage sites may undergo transformations in their form, which may not always align with their aesthetic value. Secondly, these
85 sites can exist at various scales, ranging from those covering entire landscapes, such as alluvial plains, to smaller individual features. Finally, many Quaternary geoheritage sites exhibit strong connections with human culture, encompassing archaeological, historical, architectural, and other dimensions. These sites were formed, are forming, or will be formed, concurrently with human history. Given this synchronicity, Quaternary geoheritage sites can provide geoarchaeological records of the human-environment interactions over time and document the impact of humans on this nature-culture relationship. Moreover, Quaternary geoheritage sites have inspired
90 creative ingenuity in art and cultural traditions, as exemplified by the religious and artistic significance of Mount Fuji, Japan (Chakraborty & Jones, 2018; Oguchi & Oguchi, 2010), or the importance of Holocene meteorite impact craters in Australia for Aboriginal dreamtime stories, some with an oral history dating back approximately 4500 years (Hamacher & Goldsmith, 2013).

95 Given these distinctions, many geoheritage studies (Erhartič, 2010; Moradi et al., 2021; Pereira & Pereira, 2010; Pereira et al., 2007) have treated Quaternary sites (or geomorphosites) separately from the rest of geoheritage sites. This differentiation is particularly evident in site evaluations, which place added emphasis on



100 encompassing cultural and aesthetic dimensions of Quaternary sites. However, the necessity of such a
differentiation is still debated with contradicting outcomes depending on the study. On one hand, Santos et al.
(2020) found notable differences in evaluating sites in Brazil and Switzerland between methods for general
geoheritage sites and specialised methods for geomorphosites. However, in a similar analysis, Mucivuna et al.
(2022) found no significant differences between general and specialised methods, concluding that existing
105 general methods should be used in the future to maintain consistency amongst various studies. In arid
environments, Sayama (2024) identified distinctive features when developing a method for the scientific
evaluation of Quaternary geoheritage sites, including the consideration of connections with
archaeology/anthropology, with greater importance placed on scientific knowledge. Nevertheless, the
geocultural dimension of Quaternary sites has not been studied in detail from the perspective of science
communication. Therefore, further investigation is required to understand the importance and utility of different
110 strategies, including the incorporation of the cultural dimension of Quaternary geoheritage sites.

1.2 Quaternary Geoheritage Sites in Southeast Arabia

115 Southeast Arabia is a region with a diverse array of Quaternary landscapes, including alluvial fans
(Blechs Schmidt et al., 2009; Parton, Farrant, et al., 2015a), caves (Fleitmann et al., 2003; Immenhauser et al.,
2007), palaeolakes (Rosenberg et al., 2012)), sabkhas (Heathcote & King, 1998; Matter et al., 2015), and sand
dunes (Atkinson et al., 2013; Goudie et al., 2000; Leighton et al., 2014; Radies et al., 2005). Research conducted
at these sites has significantly advanced our understanding of environmental variability during the Quaternary,
and its impact on human demographics. Throughout the Quaternary, the landscape of southeast Arabia
120 experienced alternating wetter and drier conditions, corresponding to 100k-year eccentricity (Parker et al., 2004;
Rose et al., 2019) and 23k-year precessional cycles (Parton, Farrant, et al., 2015b; Preston et al., 2015). By
integrating archaeological and palaeoclimatic data, researchers such as Parker (2009) and Parton, White, et al.
(2015) have highlighted the close correspondence between early human settlement and environmental
variability in this region. This connection underscores the importance of Quaternary palaeoenvironmental sites
125 not only important as climatic archives but also as geocultural sites with relevance for regional archaeology and
culture. This academic recognition of the connection has been acknowledged by various Quaternary scientists
(Atkinson et al., 2013; Farrant et al., 2015; Nicholson et al., 2020; Preston et al., 2015; Rosenberg et al., 2012;
Zerboni et al., 2020) who cite archaeological relevance as a primary motivation for conducting their
palaeoenvironmental research.

130 However, only a limited number of studies have considered these Quaternary sites as heritage sites requiring
and/or deserving conservation, despite various reports of their loss. A recent inventory of Quaternary
palaeoenvironmental sites in this region identified the destruction of 31 out of 234 sites (13%) along with
endangerment of 34 sites (15%) (Sayama et al., 2022), primarily due to urban development and quarrying. On
135 the scale of individual sites, Lokier (2013) and Kirkham and Evans (2019) have emphasised the endangerment
of the Abu Dhabi Sabkha, UAE, illustrating how recent developments in petroleum and civil engineering
activities have damaged over 60% of this landscape with unique heritage values. The loss of Quaternary sites
has also been documented in palaeoenvironmental studies, such as those by Atkinson et al. (2011), where sites
were destroyed by industrial development (Preston et al., 2015).

1.3 Science Communication on Geoheritage and Geosciences

145 The lack of appreciation of geosciences and geoheritage has been extensively documented from various
perspectives. Although recent global initiatives such as the Global Geoparks Network have aimed to promote
and protect geoheritage sites, visitors to geoparks often prioritise natural beauty (Štrba, 2019; Zgłobicki &
Baran-Zgłobicka, 2013) or the curiosity of exploring new places (Allan et al., 2015; Chrobak et al., 2020;
Farsani et al., 2019). On social media, the hashtag “geology” has been used approximately 80% less (617.6
million times) than “physics”, “biology”, or “chemistry” (Zawacki et al., 2022). Even when the media features
geosciences, Stewart and Nield (2013) found that topics broadcast on British television were largely limited to a
150 few popular domains, including palaeontology, volcanology, and seismology, with a range of featured



Quaternary topics mainly related to geohazards or archaeology. These findings highlight the clear need for improvement in the public recognition of geosciences, including Quaternary science.

155 Effective communication strategies have garnered attention and recognition as potential solutions to this
apparent “detachment” (Stewart & Nield, 2013, p. 699) from geosciences. As described by Illingworth et al.
(2018) and Rodrigues et al. (2023), geoscience communication is still at its infancy as an academic field with
further need for formalisation and identification of its discipline-specific challenges. Nevertheless, key issues
such as the difficulty of understanding deep time (Bowring, 2014; Trend, 2001; Warmold, 2017), unfamiliarity
with technical jargon (Kortz et al., 2017; Ren et al., 2013), and the global lack of geosciences education in
160 schools (Melendez et al., 2007; Reis et al., 2014; Subedi et al., 2020), have been identified as hurdles to wider
appreciation and understanding of geoheritage sites and geosciences.

Over the last 10–15 years, various creative approaches have been developed to enhance geoscience
communication, including information panels (Bruno & Wallace, 2019; Pasquaré Mariotto & Venturini, 2017),
165 3D models/virtual site visits (Dolphin et al., 2019; Hoblea et al., 2014), animations (Lansigu et al., 2014), poetry
(Illingworth, 2023), mobile applications (Cayla, 2014), and dance (Matias et al., 2020). Regardless of the
approach, many studies share the common theme of storytelling (Illingworth, 2023; Matias et al., 2020; Migoñ
& Pijet-Migoñ, 2017; Stewart & Nield, 2013; Van Loon et al., 2020), praising its utility in delivering
information in ways that connects with the audience cognitively and emotionally (Dahlstrom & Scheufele,
170 2018).

However, in analysing these initiatives, only a few studies have conducted qualitative or mixed-method
assessments of the impacts of interventions. Matias et al. (2020) conducted such an analysis to evaluate the
impact of a creative dance programme for elementary school education on coastal geomorphology and
175 hydrology. In this study, more than 60% of the 112 participating students preferred learning science through
movement, rather than in conventional settings. Another study by Mani et al. (2016) found a 12–17%
improvement in participants’ knowledge on volcanic hazard after playing a video game on the topic. These
impact assessments demonstrate the potential of geoscience communication but have mostly been limited to
evaluating the short-term, immediate effects of the interventions, with no data beyond those collected
180 immediately after the experience. Given the goal of geoscience communication to increase public discussion and
attention to geosciences (Illingworth et al., 2018), longer-term assessments are required to capture a more
comprehensive picture of the impact of interventions.

185 1.4 Science Communication Studies using Online Video

Videos have been used in scientific communication studies across various fields, including ecology (Ruzi et al.,
2021), climate science (Ettinger et al., 2021), and medical sciences (Dudley et al., 2023). The preference for
using videos stems from several advantages they offer. Firstly, delivering information in person or through
videos and other visual media has been found to outperform written text in 15 studies (Dudley et al., 2023).
190 Secondly, videos facilitate enhanced emotional engagement of the audience (Yadav et al., 2011) and easier
comprehension through the combination of narration and images (Moreno & Mayer, 1999). For example, in
discussing climate science, videos were found more effective than written text in communicating the consensus
amongst scientists that current climate change issues are triggered by anthropogenic activities (Goldberg et al.,
2019). Finally, as a method, videos offer the advantage of “making communication visible” (Goldman &
195 McDermott, 2007, p. 112) by capturing and enabling the analysis of the effect of a specific content in a
controlled manner, unlike personal communication, which can vary in its delivery.

Recognising the importance of videos in science communication, studies have provided guidelines for
developing effective videos. Desired features included visual attractiveness, brevity, engaging content, and
200 consideration of the audience needs and expectations (León & Bourk, 2018). Regarding the length of
educational videos, multiple studies (Guo et al., 2014; Kaim et al., 2020; Manasrah et al., 2021) have found the
optimum length of videos to be around 6–9 minutes. In Guo et al. (2014), eye-tracking of participants showed
that viewers lost attention when videos exceeded 9 minutes, with engagement lasting less than 50% of the



205 video's duration. To create an engaging video, Brame (2016) has demonstrated the need for enthusiasm from the narrator, the use of conversational language, and an emphasis on the relevance of the content.

210 Academically, videos can be used to analyse changes in opinions or knowledge after viewing (Dunn et al., 2020; Kaim et al., 2020), or to compare different communication methods, such as the relative effectiveness of various strategies in communicating a topic to the public. For example, Ettinger et al. (2021) used short videos to compare differences in viewers' reactions to videos with a pessimistic or an optimistic outlook on the trajectory of climate change. In geoscience communication, however, the utility of educational videos has seldom been studied quantitatively. One of the notable exception is Zawacki et al. (2022), who analysed the relative success of 48 geoscientific Tik Tok videos. This study found that while the most viewed videos were short clips related to news events, longer videos, which received fewer views, garnered the most user engagement. Given the demonstrated efficacy of videos in communicating science and technology, there are further opportunities to test their applicability for geoscientific topics.

1.6 Aims of the study

220 As outlined above, there is a need for further investigation into science communication regarding Quaternary science and Quaternary geoheritage. This study addresses this knowledge gap by analysing reactions to two videos by university educated, pro-nature adult residents of Oman and the UAE primarily in their 20s and 30s. The two videos were divided to one that describes Quaternary geoheritage sites of southeast Arabia with their geocultural context, and another that describes the same sites through a solely geoscientific lens. The study aims to explore the effectiveness of using educational videos and incorporating geocultural context in communicating the value of Quaternary geoheritage sites in southeast Arabia, a region where reports of destruction of Quaternary sites have been documented. The study is designed to address three primary objectives. First, it seeks to determine if videos can enhance science communication of Quaternary geoheritage sites in southeast Arabia. Second, it aims to assess how effectively the connections between Quaternary geoheritage sites and local culture (i.e. history and archaeology) can be communicated to the public in this region. Lastly, it aims to investigate whether and to what extent the inclusion of these geocultural connections improves awareness of these sites in terms of knowledge and interest, as well as fostering willingness to protect them.

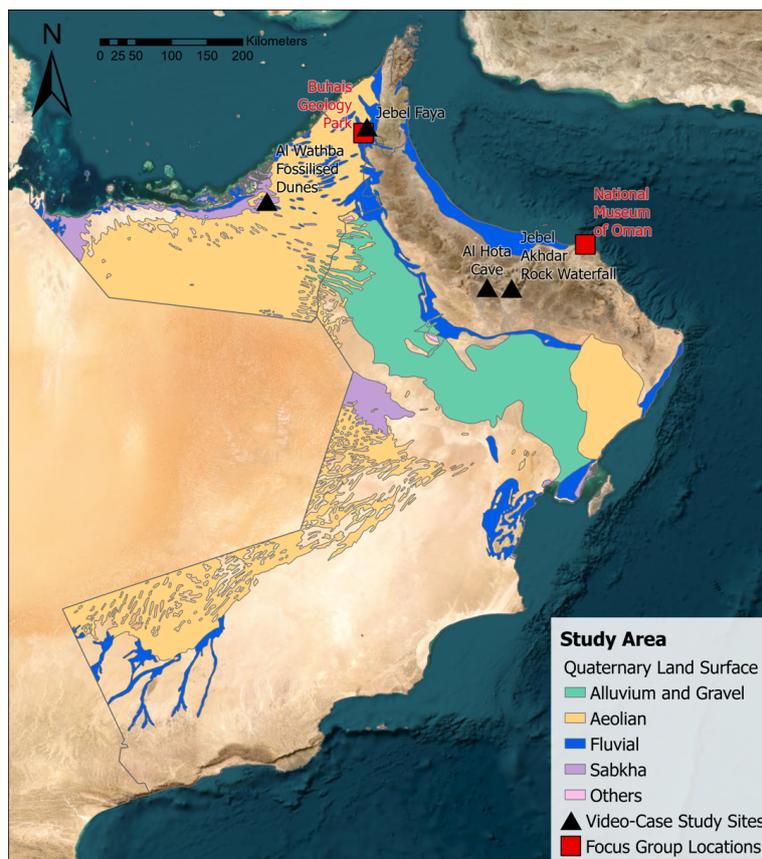
2 Regional Setting

235 Southeast Arabia (Fig. 1) is situated within the arid subtropical climate belt, spanning approximately 16°4' N and 26°4' N, with the Rub'al Khali Desert to the west and the Hajar Mountains to the east. Presently, the climate of this region is hyper-arid, characterised by an annual rainfall of less than 100 mm in most areas, except for the area around the Hajar Mountains, where it can reach up to 400 mm (Kwarteng et al., 2009). Rainfall primarily occurs during the winter across much of the region, facilitated by mechanisms such as convective rainstorms, tropical cyclones, cold frontal troughs, and southwesterly monsoons. In southern Oman, however, precipitation occurs as monsoon rainfall during the summer months (Hoffmann et al., 2016). Geologically, Quaternary deposits cover approximately 44% of the land surface (Fig. 1). The types of Quaternary landscapes in the region include aeolian (57%), alluvium and gravel (24%), fluvial (14%), sabkha (5%), and others (>0.1%). The Rub'al Khali and the Wahiba sands are the primary areas covered by aeolian sediments in this region.

245 Socioeconomically, both UAE and Oman have undergone significant major economic development over the past two decades, with GDP growth exceeding 300%, driven by the expansion of the oil industry (Pirlea, 2023a, 2023b). The economy of the region is supported by a high percentage of migrant population, standing at 41.1% in Oman and 88.4% in the UAE as of 2015 (United Nations Population Division, 2024). This economic growth has led to an improvement in educational standards in the region, with 19.1% and 47.2% of the population above age 25 attaining a Bachelor's degree in Oman (2022) and the UAE (2021), respectively (World Bank, 2023). However, opportunities for geosciences education are rather limited. In the UAE, Earth and Space Sciences are taught up to the 8th grade (13-year-old) (Al Ghfeli, 2016), but are not offered as a science elective beyond the 11th grade (16-year-old) (Ministry of Education, 2023). At the tertiary level, only three universities offer courses in geosciences. Similarly, in Oman, while environmental and natural resources are included in



science education goals, geosciences are not taught at the primary or secondary levels (Ambusaidi & Al-Balushi, 2015), and only two universities offer related courses at the tertiary level.



260 **Figure 1:** A map of southeast Arabia with Quaternary land surface characteristics, locations of case study sites in the videos, and locations where focus group meetings were conducted. Geological data derived from Pollastro et al. (1999)

3 Methodology

265 To conduct a study on Quaternary geoheritage sites in southeast Arabia using carefully produced videos that align with the audience's needs and expectations, a three-phase approach was formulated and executed between November 2022 to January 2024, as illustrated in Fig. 2.

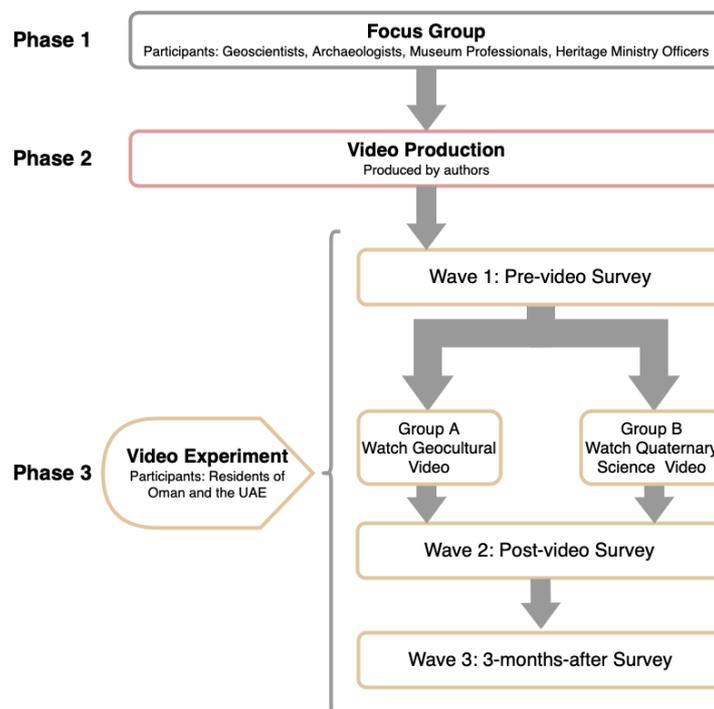


Figure 2 Flow chart describing the phases of the study

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3.1 Phase 1: Planning video contents

To determine the content of the videos, including the optimal use of the geocultural connections, two focus group meetings were conducted, once in the UAE and once in Oman. Key partners and decision makers involved in the protection and communication of Quaternary sites, including museum professionals, geoscientists, archaeologists, and officials from the Ministry of Heritage, were invited to participate. The participants were provided with a brief presentation on the relationship between archaeology, culture, and the palaeoenvironment by the authors, followed by a discussion on three main topics: their reaction to the presentation, recommendations based on past experiences, and identification of the main factors to be emphasised in the videos. The focus groups were designed to last approximately one hour and half to two hours each. Considering the linguistic abilities of the participants, the focus group in Oman was conducted in English with Arabic interpretation available upon request, while the focus group in the UAE was conducted in both English and Arabic, facilitated by an interpreter. The discussions in the focus groups were recorded, transcribed, coded, and analysed qualitatively using a combination of deductive and inductive content analysis (Bengtsson, 2016) via NVivo to categories and themes related to the research questions.

3.2 Phase 2: Video Production

Based on the insights gained from the focus group discussions, two videos were developed by the authors in collaboration with partners. The videos incorporated footage filmed by the authors, as well as videos and photographs provided by collaborators, along with Creative Commons licensed visuals and music. Each video featured voice narration in English, complemented by dialogues with experts conducted in Arabic, with corresponding translation provided as subtitles in Arabic or in English. The videos were carefully crafted to maintain a similar length, with the primary distinction between the two being an emphasis on the geocultural



295 context in one (referred to as the geocultural video), and the exclusion of the geocultural context in favour of a
more detailed description of the Quaternary science in the other (Quaternary science video).

3.3 Phase 3: Video experiment

300 An online experiment was conducted using the videos produced in the second phase of the study. Participants
were recruited based on the inclusion criterion of being residents of the UAE or Oman. Recruitment efforts
included calls at universities, as well as emails and posts through nature societies, museums, and social media
platforms. The experiment consisted of a registration process and three waves of surveys, including a
questionnaire administered before, immediately after, and three months after watching the video. Upon
305 completion of the pre-video questionnaire, participants were randomly assigned to either the treatment group,
which received and watched the geocultural video, or the control group, which received and watched the
Quaternary science video. All procedures of the experiment were conducted using online questionnaires, and
instructions were provided in both Arabic and English.

310 The three questionnaires aimed to assess the participants' knowledge and interest in geoheritage sites,
Quaternary geoheritage sites, archaeological sites, and the relationship between Quaternary geoheritage sites
and archaeological sites. The Quaternary geoheritage sites section included a quiz where participants were
required to select photos of Quaternary geoheritage sites, while the geocultural connection included questions to
identify the correct relationship described between the two disciplines. Both quiz questions were presented as
315 multiple-choice questions with multiple correct and incorrect answers. Wave 1 additionally included questions
about participants' level of knowledge and interest in natural heritage sites to gauge their predisposition towards
nature and nature conservation. In Wave 3, additional questions were included to assess participants'
impressions of the video and the impact, aiming to understand memorable features of the video and whether
watching it led to further engagement and/or action by the viewers.

320 Each questionnaire was designed to take between 5–10 minutes to complete. Most questions utilised a five-point
Likert-like scale, with exceptions including Yes/No questions, text-entry questions (mostly in Wave 3 regarding
impressions and impact of videos), multiple-answer questions (including quizzes), and questions on the
importance of protecting certain types of sites, which were presented as a 10-point slider-scale. Text-entry
325 questions on naming Quaternary geoheritage sites were included to avoid revealing which sites are considered
Quaternary sites through multiple-choice questions. The full questionnaires are available in Supplement i.

3.4 Data analysis

330 The data collected from the questionnaires underwent quantitative and qualitative analysis, based on the nature
of the questions. Descriptive and statistical analyses, including hypothesis testing where applicable, were
employed. The statistical analyses were conducted using paired t-tests and difference in differences analysis.
Although some discussion continues on the treatment of aggregated Likert-type data as an ordinal scale rather
than discrete categories (Bishop & Herron, 2015), this study employed parametric methods to analyse this data
335 in line with other studies such as De Winter and Dodou (2010).

Quantitative methods were applied to Likert scale items and quiz scores, while a qualitative assessment was
conducted for responses to text-entry questions. The qualitative analysis involved deductive and inductive
content analysis using NVivo to categorise themes related to the research questions and emerging themes from
340 the responses. The predetermined themes included those related to the key points mentioned in the focus groups,
and options indicated in the questionnaire as multiple-choice questions.

Statistical analyses followed methods commonly used in Randomly Controlled Trial (RCT) experiments, where
both treatment and control groups are present. In this study, both groups viewed a video about Quaternary
345 geoheritage sites, with the control group watching a video focused solely on Quaternary science and the
treatment group watched a video with geocultural information included. While a third control group watching an
unrelated video would have been ideal, practical constraints limited this option. However, the absence of a true



350 “baseline” control group did not hinder the effects of the treatment – i.e., the inclusion of geocultural
information in the video. Since the members of the control group had also watched a relevant video and we
would expect it to have an effect on their responses in the post-treatment (Wave 2) and follow-up (Wave 3)
surveys, it was determined that the most appropriate method for analysing this data would be a difference-in-
differences analysis with fixed effects for the treatment group and the survey wave. Difference-in-differences
analysis is a specific type of fixed effect analysis that is commonly used to evaluate treatment effects in natural
355 experiments (see Abadie (2005) for a detailed discussion). It allows for the assessment of treatment effects over
time, even when there are underlying differences between observed groups and timeframes. The strong
assumption of difference-in-differences is that of parallel trends, which posits that changes over time would
have been similar between groups if not for the treatment effect. In other words, while the groups may have
started differently and experienced changes over time, these changes would have followed parallel trajectories in
the absence of treatment. Given the design of this experiment, we found no cause to believe that the parallel
360 trends assumption would be violated in this case. Statistical analyses were performed using R Statistical
Software (v4.4.0; R Core Team 2024) and the *tidyverse* environment (v2.0.0, Wickham et al 2019). Fixed
effects and difference-in-differences modelling were performed using the *fixest* R package (v0.12.1; Berge
2018).

365 The full reporting of the results of differences-in-differences analyses is provided separately in Supplement ii.

For each survey item, the responses in each wave of the survey were initially compared to the Wave 1 responses
using a t-test to determine if there was a statistically significant difference between waves. Subsequently,
difference-in-differences was conducted to assess the effects of the treatment. It is important to note that even in
cases where the t-test for the overall dataset showed no statistical significance, the difference-in-differences
370 analysis could reveal a significant difference between treatment and control groups. This is because the
treatment group may have a positive effect while the control group has a negative effect, potentially cancelling
each other out in the overall population analysis.

375 Finally, the data were subdivided into specialist and non-specialist respondents. The specialist group comprised
of respondents who were either geology students or professionals in a geology-related field, while the non-
specialist group comprised all other respondents. This division aimed to examine whether the treatment effect
varied based on the respondent’s level of expertise or prior subject knowledge. The difference-in-differences
analysis was then re-run for both groups, and the results were used to conduct direct comparisons of the
380 treatment effect between specialist and non-specialist respondents.

4 Results and Discussion

4.1 Phase 1

385 The focus group in the UAE took place in November 2022 at Buhais Geology Park, and the focus group in
Oman was conducted in December 2022 at the Oman National Museum. As demonstrated in Table 1, in the
UAE, participants included an archaeologist, two staff from a geology museum and two staff from an
archaeology museum. In Oman, the focus group was attended by two archaeologists, two staff from the National
390 Museum, an officer from the Ministry of Heritage, and two geologists. Both genders and nationals and non-
nationals were intentionally selected to ensure diversity among participants.

395



Table 1 Participant profile for the focus groups conducted in this study

	Participants	Number	Non-nationals
UAE	Archaeologist	1	1
	Staff from Buhais Geology Park	2	0
	Staff from Mleiha Archaeology Center	2	2
Oman	Archaeologist	2	1
	Geologist	2	0
	Staff from the National Museum of Oman	2	0
	Staff from Ministry of Heritage	1	0

400 The focus group discussions lasted approximately two hours and seven minutes in the UAE and one hour and 38 minutes in Oman. From the coded transcripts, seven main themes emerged, summarising the key points discussed. Overall, the focus groups highlighted the importance of striking a delicate balance between aesthetic appeal, scientific rigor, and cultural resonance in creating an effective video for communicating Quaternary geoheritage sites. It was also emphasised that the narrative should be designed with care to engage and enhance audience understanding.

405

4.1.1 Visual preference

410 The focus groups included in-depth discussions about the most suitable visuals to include in the video. The consensus view favoured aesthetic images over detailed scientific visuals to engage audiences with Quaternary geoheritage sites. Additionally, in the UAE, there was widespread approval for selecting scientific images that also had aesthetic appeal. Participants highlighted the crucial role of captivating visuals in capturing initial interest, particularly among non-specialists. One participant aptly summarised this sentiment, stating “for me it's the image from the first glance, you can decide whether you will like it or not like it. You are interested, you will go further, or you withdraw.” However, participants also recognised the importance of incorporating scientific imagery strategically to explain key processes and explore the values of sites beyond their aesthetic beauty. This balanced approach was seen as essential for providing a comprehensive understanding of Quaternary geoheritage sites.

420 **4.1.2 Financial matters**

The discussion on whether to include the economic potential and benefit of protecting Quaternary sites generated varied opinions within the focus groups. In the UAE, participants unanimously advised against emphasising economic benefits in a video targeting non-specialists, despite a shared recognition of its importance. Conversely, in Oman, the participants overall supported the inclusion of the economic relevance, although two participants highlighted the importance of not making this element the video's main message. In summary, there was a recognition of the importance of financial aspects to make the topic more relatable to the audience, especially for ones living near the sites. However, there was an agreement that economic considerations should be introduced sporadically in the video without overshadowing other content.

430 **4.1.3 Need to raise awareness**



435 The importance of raising awareness about Quaternary geoheritage sites received unanimous support in both
focus groups, with no negative opinions. Participants underscored the prevalent lack of awareness among the
local people and communities regarding the importance and significance of the regional Quaternary sites and
advocated for clear, accessible communication with little to no technical jargon. However, discussions also
emphasised the need to consider the underlying motivations and objectives of any awareness-raising efforts.
One participant highlighted this by commenting: “the question that we always forget is, why do we want people
to be aware of those sites, maybe it's actually good for them not to be aware of this kind of stuff.” A clear
message describing why the topic is relevant for the audience was identified as an essential component in the
440 video.

4.1.4 Narrative

445 Participants unanimously endorsed the need to include a compelling narrative to engage audiences. Two distinct
concepts emerged in this regard. First, participants highlighted the potential of narratives that stimulate the
audience's imagination and allow them to envision the past. Second, the participants agreed that the use of the
geocultural context can be an effective way for viewers to create personal ties with the subject. Notably,
suggestions were made to incorporate culturally relevant anecdotes, such as verses from the Quran with
resonance to historical climate change in Arabia, to enhance viewer engagement and comprehension.

450

4.1.5 Local people, culture, and knowledge

455 In both focus groups, the idea of involving older/respected figures to narrate the cultural relationship between
humans and the regional landscape was discussed as a potentially effective strategy for introducing Quaternary
geoheritage sites. The concept of cultural identity was highly emphasised and supported in these discussions.
Four participants shared anecdotes in which a site's relevance to the local community significantly influenced
how people perceived its importance. Positive responses to this idea were not limited to participants who were
nationals of the UAE or Oman but were emphasised more by non-national participants.

460 In Oman, there was a discussion on the importance of the storyteller's identity, with an agreement that a foreign
researcher presenting this idea is not negative, but having a local person telling the story would be preferable
whenever possible.

465 Although the introduction of the geocultural context by local figures was supported, the use of interviews in the
videos evoked mixed views. Four participants in the focus group in Oman were enthusiastically supportive of
using interviews, noting that they lend scientific information with more authority in delivering the message.
Additionally, proponents of interviews mentioned how voices of respected (widely supported) or locally based
figures can make the subject more personal and relatable. However, in the group in the UAE, participants
470 unanimously spoke against the idea of interviews, expressing concerns that they could make the video resemble
a “lecture” or a “documentary”, which people might find “boring”. Even in Oman, one of the participants was
wary of the use of interviews, suggesting they should be very brief and scattered even if used at all. A similar
sentiment was expressed by the supporters of the interview, leading to the conclusion that the interviews, if
included, should be few and short.

4.1.6 Scientific Information

475 In each of the focus groups, some participants (three in the UAE, one in Oman) initially considered scientific
information the most important factor to introduce in the video. Overall, there was no disagreement about the
importance of conveying the general idea of what makes each site scientifically significant. However, during the
480 discussions, different ideas emerged regarding the depth to which the video should engage with scientific
information. While there was overall agreement on the value of the scientific information in introducing the
main features of the site and justifying why it is worthy of protection, opinions diverged on the level of detail
that should be included. While two participants supported providing detailed scientific information, others were
more supportive of presenting simple, general ideas rather than delving into the specifics.



485

4.1.7 Sequence of Presentation

At the end of the focus groups, strategic discussions revolved around the optimal sequencing of elements in the video. Participants generally favoured starting with aesthetically pleasing images to captivate the audience, particularly those who are not inherently interested in geology. Nearly all participants, with the exception of one who did not express an opinion, agreed that if interviews were to be included, they should not be placed at the beginning of the video to avoid giving it a lecture-like feel.

There was also a consensus on the need for a simple description of the general concept of geoheritage. As one participant mentioned, “images without information would not mean anything to the viewers”, highlighting the importance of providing a straightforward explanation of the general concept without using technical jargon. In Oman, the focus group proposed the idea of introducing the superiority of the region’s Quaternary geoheritage by describing what makes it special or unique. Additionally, participants widely supported the idea of creating a connection (e.g. cultural, economic) between the audience and the subject matter. However, there was agreement that the economic aspect should be introduced after the general idea, so as not to overshadow other aspects of the video’s message.

Discussions also favoured the idea of introducing deeper details of the relevance of Quaternary geoheritage sites (cultural, economic, scientific, etc.) later in the video, once the viewers gain a general understanding and developed a connection with the subject. The use of case studies was supported by many participants, although two participants in the UAE opposed to this idea, identifying case studies as the least important element.

4.2 Phase 2

Two videos were produced based on the best practices from science communication research and the insights gained from the focus groups. The videos are available via the links (Control Video: <https://ora.ox.ac.uk/objects/uuid:e14384cb-68fa-45f1-914d-3204e05bb3ea>, Treatment Video: <https://ora.ox.ac.uk/objects/uuid:ee8c3f2a-1888-4967-a104-b5799ba68d8d>). Table 2 outlines the contents and duration of the two videos.

Table 2 Contents and duration of the two videos produced for the study. The asterisk indicates contents with different narration/dialogue between the two videos.

	Geocultural video (s)	Quaternary Science Video (s)
Introduction	30	36
Introduction of narrator and title	22	22
Geoheritage sites–Global	17	17
Geoheritage sites–SE Arabia	29	31
History–Earth’s geology	12	14
Introduction to Quaternary geoheritage (scenery)	16	18
Introduction to Quaternary period (scientific)	11	15



Examples of Quaternary sites in SE Arabia	15	15
Social relevance of Quaternary sites for geohazards	14	16
Quaternary climate change*	39	47
Implications for the Quran	30	0
Archaeological relevance	38	0
Example 1, travertine–non-cultural* (dialogue in Arabic)	31	52
Example 1, travertine–cultural (dialogue in Arabic)	8	0
Geoheritage conservation frameworks and geotourism (economic relevance)	30	34
Example 2, fossilised dunes* (dialogue in Arabic)	31	46
Example 3, Al Hoota Cave	32	36
Example 4, Jebel Faya–non-cultural*	18	77
Example 4, Jebel Faya–cultural	64	0
Endangerment of Quaternary sites	19	19
Summary	33	35
End credit	6	6
Total duration	545	536

520

The duration of the two videos is different by 9 seconds at 9 minutes 5 seconds for the geocultural video and 8 minutes 56 seconds for the Quaternary science video. The length of the videos falls at the longer limit of the 6–9 minute length range suggested in the literature for optimal engagement. After producing the videos with distinctive elements for each, the difference in the length of the video was minimised by elongating the transition elements in the Quaternary science video, which included 153 words (in English translation) less of dialogue than the geocultural video. The total length of sections introducing the geocultural context in the geocultural video was 140 seconds, accounting for ≈26% of the entire video. The geocultural elements included the description of the relationship between findings from Quaternary science (palaeoenvironmental records) and a verse in the Quran, an introduction to the relevance of Quaternary science for archaeology, and cultural connections at example sites 1 and 4, through agriculture and archaeology, respectively. The distinctive elements of the Quaternary science video included additional scientific information related to example sites 1, 2, and 4, related to the formation of the sites and descriptions of a sediment cross section. The videos did not include a formal interview but included a dialogue with local geologists from a site each in Oman (example 1) and the UAE (example 2), who explained the significance of the respective site.

535

The videos were piloted and approved by the participants of the focus group on cultural/social content and scientific accuracy before being distributed to the study participants.



540

4.3 Phase 3

4.3.1 Participant Profile

545 After excluding blank responses and responses from participants who do not meet the study inclusion criterion, the study gathered 211 registrations, 160 responses to Wave 1 (pre-video), 104 responses to Wave 2 (post-video), and 82 responses to Wave 3 (3-months-after). The breakdown of participants is demonstrated in Table 3. The drop-out rate of these surveys is within or better than the expected range of around 30–40% (Grønmo, 2019), with an especially low rate between Waves 2 and 3 at 21%. The results and analyses below consist of findings from the data of 104 participants who completed the questionnaires at least up to Wave 2. The term “participants” will refer to these 104 participants hereafter. Given the total population of southeast Arabia at 14.1 million, according to Yamane’s formula for sample size (Yamane, 1967), 104 participants are able to represent the population of this region at a margin of error at $\pm 9.8\%$. For reference, to achieve an error margin of $\pm 5\%$, a sample size of about 400 would have been required.

555 **Table 3 Breakdown of video study participants. All questions in the survey were optional, leading to some missing responses**

		Total	Specialist	Non specialist	Student	Non student	UAE resident	Oman resident	National	Non national
	Wave 1	160	73	87	109	51	64	94	128	31
Wave 2	Control	49	26	23	40	9	16	33	39	10
	Treatment	55	22	33	39	16	24	31	43	12
Wave 3	Control	38	22	16	33	5	27	11	31	7
	Treatment	44	19	25	33	11	18	26	33	11

560 The responses were collected from 55 participants in the treatment group and 49 participants in the control group for Wave 2, and 44 participants in the former and 38 participants in the latter for Wave 3. The residence of the participants was split 64 in Oman and 40 in the UAE, and their nationality consisted of 61 Omanis, 21 Emiratis, and 22 others. The ratio of nationals over non-nationals in each country is higher than the demographics of either country, but the ratio of non-nationals was higher in the UAE group, in correspondence with the country’s higher ratio of non-nationals within the overall population.

565 The profession of the participants included 78 university students, of whom 47 study geosciences and 31 study other subjects. Of the 23 employed participants, only one worked in geology related fields. There were two unemployed and one retired participant. In analysing the data, geosciences students and professionals were considered domain specialists (n=48), and the others were considered non-specialists (n=56), to distinguish results based on the participants’ familiarity with geology. Between the specialists and the non-specialists, there was a statistically significant difference in their pre-treatment self-reporting of knowing any geoheritage sites (t-test $p < 0.001$) or Quaternary geoheritage sites (t-test $p = 0.051$ in Chi-squared test and $p\text{-value} = 0.035$ in Fisher’s exact test). However, there was a difference in the number of specialists who knew some geoheritage sites (95%) compared to those who knew Quaternary geoheritage sites (50%), showing that the recognition of Quaternary sites in southeast Arabia was relatively low, even amongst the specialist population.

575



580 Regardless of their familiarity with geoh heritage sites or Quaternary geoh heritage sites, the respondents had a very high predisposition to nature conservation in general, with a mean of 9.2 (out of 10, SD=1.4) in rating the importance of protecting natural heritage sites. Similarly, even before watching the video, the respondents reported a high level of support for protecting geoh heritage sites (mean=9.0, SD=1.7) and Quaternary geoh heritage sites (mean=8.6, SD=2.0), despite a consistent decrease in the mean and increase in the standard deviation as the category became more specific.

585 Although this study originally aimed to target the general public, the participant profile is limited to a highly educated, nature-loving, and young portion of the general population. This restricted sample demographic, however, fits well with the common description of potential targets for geotourism identified through studies conducted in various geographic and cultural settings around the world (Dowling & Allan, 2018; Kim et al., 2008; Štrba, 2019).

590 4.3.2 Impressions and impact of the video after 3-months

The questions asked exclusively in the Wave 3 revealed different impressions and interactions that the participants had toward/with the video and its contents, based on the video assigned. In terms of the number of times that the participants watched the video, the two groups did not differ much with a little less than half of both groups (T: 48%, C: 47%) watching the video more than twice. However, the self-reported memory of the contents of the video was higher for the treatment group, with 25% of the participants reporting that they remember the video well, as opposed to 16% in the control group. For the video length, the overall impression is that the length was just right, supported by 80% of all Wave 3 participants. However, 17% (14) mentioned that the video was a little too long. Of the participants who gave this answer, 64% were from the control group. In ratio, compared to the overall size of each group, those who thought the video was a bit too long in the control group was 11% higher (24%), compared to those in the treatment group (13%).

605 For the impact of the video, a curious result was found in the aspect of video that left the strongest impression on the participants. The “importance of protecting geoh heritage sites” was the most selected by the treatment group (13), but the “Connections between Quaternary geology and culture/archaeology” (10) was favoured the most by the control group, despite the lack of any explanation about these connections in the video. As seven of these 10 participants who gave this answer indicated that they conducted further research into the contents of the video, this result could be due to the independent knowledge gained beyond the video. At the same time, it could be the case that the participants found cultural and archaeological connotations in the video, even without having it introduced explicitly. In turn, for the treatment group, the geocultural connections was joint third (8), which could be showing that the message of the video steered the audience more towards thinking about the protection of sites overall, rather than focusing on particular elements. Finally, when asked the effect of the video towards their level of interest in Quaternary geoh heritage sites, 91% of the respondents (72) reported that it made them either “a little more interested” (16, 20%) or “more interested” (56, 71%). The ratio of those who answered positively was 4% higher for the treatment group. It should be noted, however, that none of the differences described in this section were statistically significant. Qualitative analyses toward open-answer questions and statistical analyses on other questions have been used to provide additional context to these results.

620 4.3.3 Qualitative analysis on impressions toward the video

625 Of the 82 respondents to the 3-months-after questionnaire, 46 provided open-ended answers on things they liked or learned from the video. The responses consisted of 20 answers from the treatment group and 26 from the control group. The answers were split into 19 that included comments only on their learning experience, eight only on things they liked, and 19 that provided both aspects. For the parts liked by the audience, the learning experience (13), clarity of the contents (8), and the beautiful scenery (8) were mentioned most frequently. The clarity of the video was praised by multiple participants as “accessible”, “easy”, or “enjoyable”. Moreover, although mentioned only by four participants, the dialogue with the local geologists received enthusiastic support with a sense of appreciation for the engagement. In terms of the learning experience, a notable tendency was the relative lack of mentions related to Quaternary geoh heritage sites (6), as opposed to general geoh heritage



630 sites (19). This may indicate that the video was effective in communicating on geoheritage sites in general, but
did not leave as much of an impression about Quaternary sites in particular.

Similarly, 33 open-ended answers were collected on points that the video could improve on, of which 13 did not
include any suggestions. The 20 answers with points for improvement consisted of eight from the treatment
635 group and 12 from the control group. The most frequently indicated suggestion was related to reducing the
length of the video, which was mentioned by eight participants. These comments were provided by seven
participants who watched the Quaternary Science video, with only one participant from the treatment group
suggesting this point. On the contrary, three comments, all from the treatment group, suggested the benefits of
640 providing more information. Other themes of the comments included points related to the production value,
including the adding of a short animation (2), improving the narration (2), and improving the overall quality (3)
as well as the delivery of the contents by providing less complexity (3), and making the content more interesting
(5).

In general, the qualitative analysis of responses to open-ended questions indicates a positive reception of the
645 videos among participants. A notable trend emerges from the control group's feedback, which emphasises the
desire for a shorter video length. This observation aligns with the earlier quantitative findings, wherein a higher
percentage of the control group expressed a perception of the video being slightly lengthy, thereby reinforcing
the notion that the treatment video effectively maintained audience engagement. Moreover, these insights
650 underscore the value of engaging relevant stakeholders in video production process. Key themes identified as
significant in the focus group discussions, including the importance of employing clear language, of the use of
aesthetic imagery and strategic incorporation of dialogues with locals, were highlighted as positive aspects by
participants across both groups.

655 4.3.4 Statistical Analysis: Quaternary geoheritage

4.3.4.1 Self-Reported Interest in Quaternary Geoheritage

This question measured participants' interest in learning about Quaternary geoheritage sites using a five-point
scale, from 0 to 4. As shown in Fig. 3, the study showed a statistically significant (t-test $p = 0.0011$) increase in
660 self-reported interest in the post-treatment wave. However, this effect disappeared by the follow-up survey, with
no statistically significant difference found in the distributions of the pre-treatment and follow-up waves (t-test p
 $= 0.55$). Difference-in-differences analysis revealed that subjects in the treatment group reported higher
increases in their post-treatment interest levels than those in the control group (DiD coefficient = 0.067, $p <$
0.001). Although the effect was small, it appears to have been sustained over time, remaining statistically
665 significant in the 3-months-after survey (DiD coefficient = 0.073, $p < 0.001$). This finding contrasts somewhat
with the self-reported gain in interest in Quaternary geoheritage sites observed in Wave 3, as discussed in the
previous section. One plausible explanation for this discrepancy could be the difference in the disparity could
stem from a distinction between overall interest in the topic and the interest in learning about the Quaternary
geoheritage sites. While participants may have experienced a general uptick in interest, it may not necessarily
670 have translated into a desire to delve deeper into Quaternary geoheritage sites.

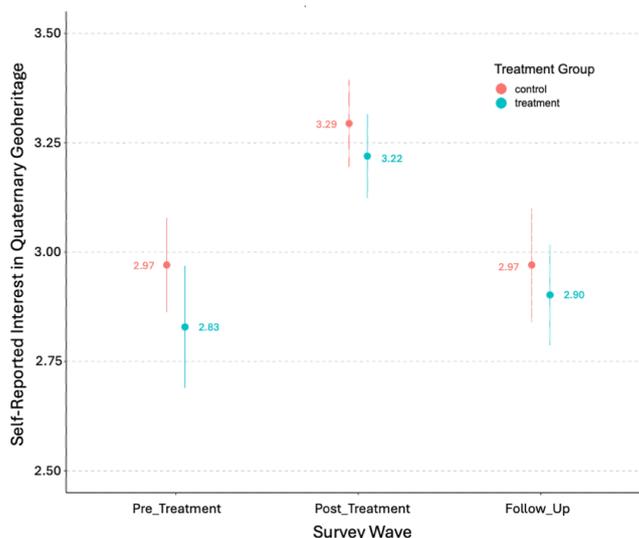


Figure 3 Interest in Quaternary Geoheritage

675

Nevertheless, the treatment effect displayed inconsistency across the specialist and non-specialist respondents.

680 Among specialists, the treatment group reported a marginally higher increase in interest post-video (DiD coefficient = 0.056, $p < 0.001$), accompanied by a slightly lower increase in the follow-up survey (DiD coefficient = -0.056, $p < 0.001$). Conversely, among non-specialists, the treatment group demonstrated a very small increase in interest compared to the control group in the post-treatment survey (DiD coefficient = 0.003, $p < 0.001$), followed by a notably larger increase by the time of the follow-up survey (DiD coefficient = 0.155, $p < 0.001$). This discrepancy implies that the treatment material may have been effective in not only initially piquing the interest of non-specialists but also in sustaining their curiosity over the longer term. This outcome suggests that the inclusion of the geocultural context in the treatment aided the audience, particularly non-specialists, in maintaining their engagement and fostering a sense that there is more to explore regarding Quaternary geoheritage sites.

690 4.3.4.2 Self-Reported Knowledge about Quaternary Geoheritage

This question asked the participants how much they know about Quaternary geoheritage sites, on a five-point scale from 1 to 5. The study found a statistically significant increase in respondents' self-reported knowledge in the post-treatment survey (t-test $p < 0.001$). While some degree of mean reversion was seen in the follow-up survey, the uplift remained significant (t-test $p < 0.001$) at this point (Fig. 4).

695

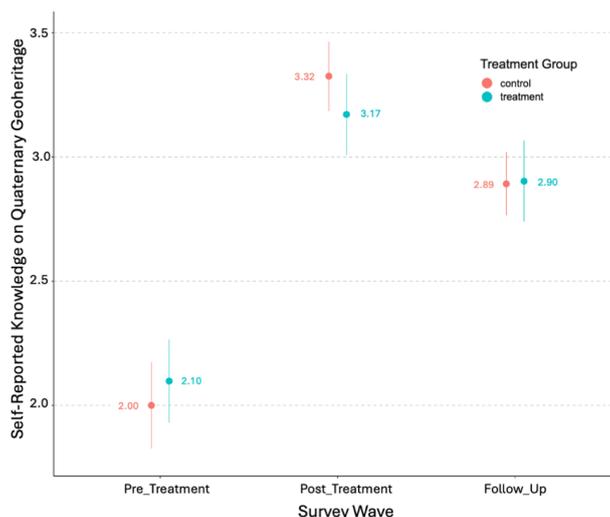


Figure 4 Knowledge about Quaternary Geoheritage

700 Difference-in-differences analysis conducted on the two groups revealed a statistically significant and negative effect associated with being in the treatment group (DiD coefficient = -0.160, $p < 0.001$). In essence, participants in the control group reported larger increases in their knowledge compared to those in the treatment group. This effect was strongest in the post-treatment survey (DiD coefficient = -0.251, $p < 0.001$), but also persisted at a lesser extent in the follow-up survey (DiD coefficient = -0.087, $p < 0.001$). The difference in self-reported knowledge increase may be explained by the diversified focus of the treatment video, which introduced

705 viewers to a wider range of topics and made them feel less informed about Quaternary geoheritage specifically than those who watched the more focused control video. In self-assessing the knowledge gained from the video, the in-depth scientific information (e.g. explanation of a cross section) led to an enhanced perception of the participants on the extent to which they know about Quaternary geoheritage sites. Nevertheless, the overarching findings suggest that the video effectively heightened awareness of Quaternary geoheritage sites, at least at a

710 superficial level.

The negative results among treatment group members were found in both specialist and non-specialist respondents (Table 4). Specialists reported a higher uplift in knowledge after viewing the video than non-specialists, but this effect was consistently weaker in the treatment group than in the control group across both

715 sets of subjects. The relative ease with which those with some degree of specialist knowledge could gain more knowledge about Quaternary geoheritage corresponds well with the findings in general geosciences communication literature, that many non-special people (including students) find geology and its deep time concept difficult to approach (Trend, 1998, 2001) and find a high barrier in starting to learn about the field (Rogers et al., 2024).

720

Table 4 Self-reported knowledge on Quaternary Geoheritage - Results of DiD by Expertise Level. p-values for DiD coefficients are represented in parentheses.

	Specialist	Non-Specialist
DiD coefficient:		
Post-Video Survey	-0.302	-0.106
(p-value)	(<0.001)	(<0.001)



DiD coefficient:	-0.222	-0.101
Three-months-after Survey	(<0.001)	(<0.001)
(p-value)		

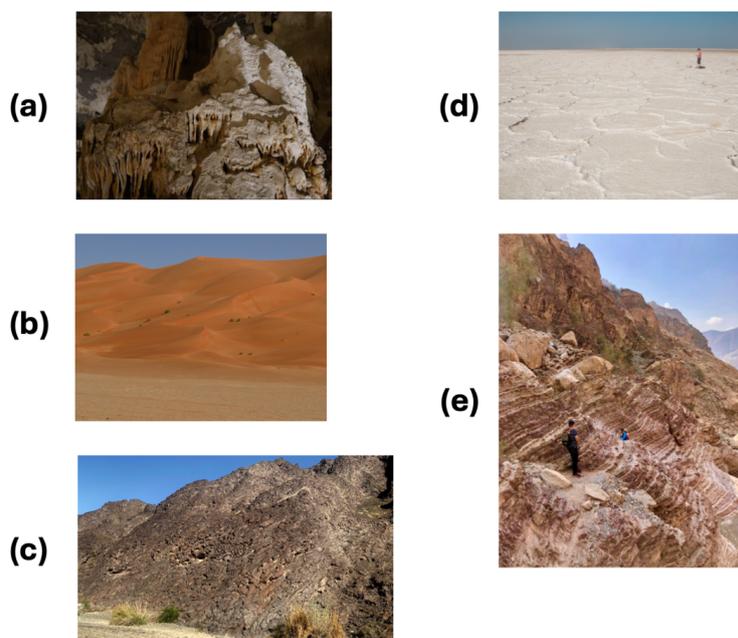
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4.3.4.3 Photo Quiz Scores for Quaternary Geoheritage Sites

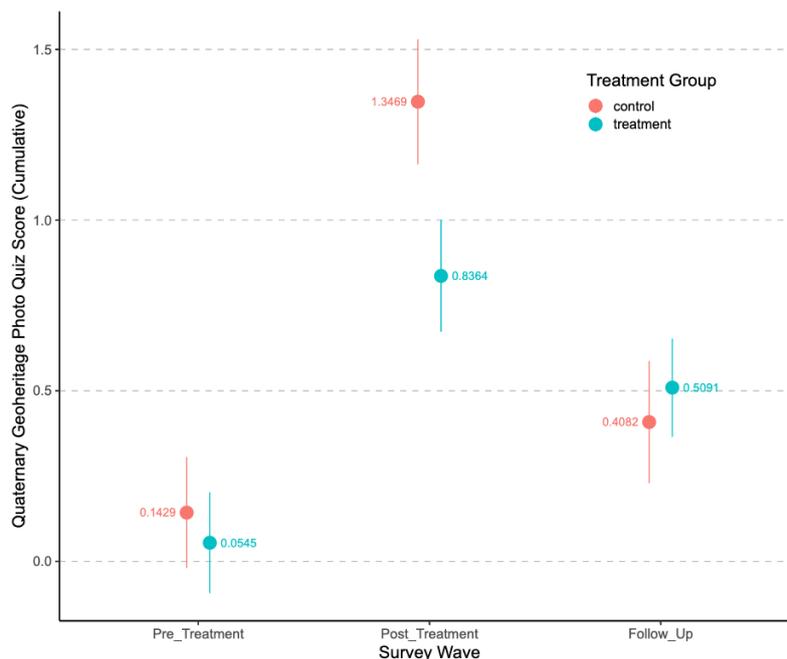
In this quiz, participants were tasked with identifying photos of sites they believed to be Quaternary geoheritage sites. The photos used for this quiz is shown on Figure 5. Among the five options provided, three were correct while two were incorrect. The quiz score was calculated by subtracting the number of incorrect answers from the number of correct answers. This method was chosen to mitigate potential bias from participants selecting numerous answers, which could skew data collection if only correct answers were counted. Analysis of the resulting variable revealed a very significant (t-test $p < 0.001$) increase in respondents' scores in the photo quiz immediately after viewing the post-video (Fig. 6). As expected, there was a high degree of mean reversion observed by the time of the follow-up survey. However, the scores remained significantly higher than those recorded in the pre-video quiz (t-test $p = 0.013$), indicating that respondents retained knowledge acquired from the video for several months.

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735



740 **Figure 5** Photos used in the quiz to identify Quaternary geoheritage sites. The correct answers are (a) [cave features], (b) [sand dunes] and (d) [sabkha] (Photo Credit: [a], [c] photo by first author, [b] Professor Andrew Goudie, [d] Professor Stephen Lokier, [e] Dr Knut Bretzke)



745

Figure 6 Quaternary Geoheritage Photo Quiz Score

The difference-in-differences analysis conducted on this data corroborated the observations made from the visual examination of Fig. 6. It revealed that the treatment group had markedly less improvement than the control group in the photo quiz immediately after the video (DiD coefficient = -0.422, $p < 0.001$), but by the time of the follow-up survey, these differences had been erased and even partially reversed (DiD coefficient = 0.189, $p < 0.001$). Subjects who viewed the treatment video showed greater knowledge retention in the follow-up survey than those who viewed the control video, despite the control group's significantly better performance in the immediate post-video quiz. This could be attributed to the different focus of the treatment video making its content more memorable at the expense of giving more in-depth information. Given the focused and in-depth information about Quaternary geoheritage sites in the control video, those who viewed this material were more effective at identifying Quaternary geoheritage sites immediately after viewing the material. However, after three months, the seemingly more memorable nature of the treatment video levelled out the performance of both groups, with the treatment group even pulling marginally ahead in the quiz task at this point.

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The above-mentioned result, however, appears to have been primarily influenced by the responses of the specialist respondents in the survey, as indicated by the distinct outcomes observed in the separate difference-in-differences analyses for specialists and non-specialists presented in Table 5. While the effect in the immediate post-video quiz scores was largely consistent across both specialist and non-specialist respondents – with the treatment group performing less favourably than the control group in both cases – their performance in the follow-up survey diverges significantly. Among specialists, those who viewed the treatment video retained significantly more knowledge by the follow-up quiz compared to those who viewed the control, whereas among non-specialists, those who viewed the treatment video continued to underperform those who viewed the control video (albeit by a very small margin in the follow-up). This outcome suggests that while the treatment video may not have been as effective in imparting knowledge about Quaternary geoheritage sites, it did contribute to better memory retention among individuals who already possessed a foundational level of domain specific knowledge. For participants without a background in geology within the treatment group, a similar rationale may account for the result.

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770



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Table 5 Photo Quiz Score- DiD Analysis by Expertise Level. p-values for DiD coefficients are represented in parentheses.

	Specialist	Non-Specialist
DiD coefficient: Post-Video Survey (p-value)	-0.458 (<0.001)	-0.386 (<0.001)
DiD coefficient: Three-months-after Survey (p-value)	0.490 (<0.001)	-0.045 (<0.001)

4.3.4.4 Protection Priority for Quaternary Geoheritage Sites

780 This question asked participants to answer how important it is to protect Quaternary geoheritage sites on a 10-
 point scale, ranging from not important at all to top priority. There was a significant (t-test $p < 0.001$) increase in
 respondents' rating of how much protection of Quaternary geoheritage sites should be prioritised in the post-
 video survey (Fig. 7). However, these scores saw a high degree of regression to the mean by the time the follow-
 up was conducted three months later. While the priority scores in the follow-up did have higher means than in
 the pre-video survey, the overall difference was not statistically significant (t-test $p = 0.142$). It is worth
 785 reiterating that the initial scores were quite high, with means of around 8.5 (the highest possible rating being 10)
 and very few respondents rated these sites as a low priority for protection.

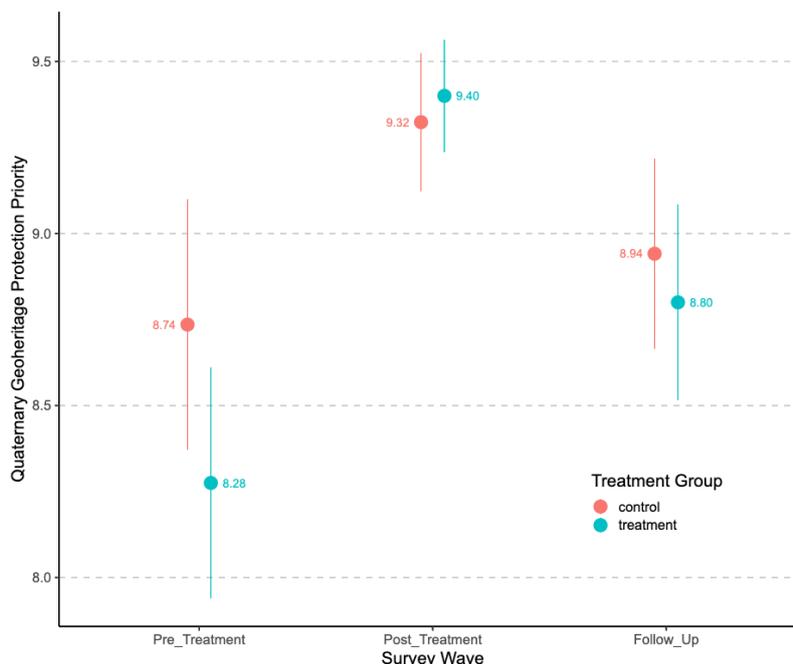


Figure 7 Quaternary Geoheritage Protection Priority

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The difference-in-differences analysis reveals that subjects who viewed the treatment video were significantly more likely than those who viewed the control video to increase the score they gave for protection priority for Quaternary geoheritage sites (DiD coefficient = 0.428, $p < 0.001$). This effect is not only apparent immediately after watching the video (DiD coefficient = 0.537, $p < 0.001$), but persists strongly in the follow-up survey (DiD coefficient = 0.319, $p < 0.001$), suggesting that the treatment material was effective at convincing viewers of the importance of protecting these sites, with that updated belief being carried through for at least three months. This is consistent with the finding that “importance of protecting geoheritage sites” was the video theme which left the biggest impression on the largest number of participants in the treatment group.

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The effect mentioned above is replicated across both specialist and non-specialist respondents in the survey (Table 6) – in both cases, the treatment group had a larger increase in their protection priority score than the control group, both in the post-video and follow-up surveys. The effect size, however, is notably larger for the non-specialist respondents, being almost double the effect size for specialists. This may suggest that the treatment material is especially effective at convincing non-specialist audiences of the value of protecting quaternary geoheritage sites. However, it should also be noted that specialist respondents on average gave a higher score for protection priority in the pre-video survey (their mean score being 9.13, versus 8.23 for non-specialists), which may serve to reduce the effect size in this group as many respondents were already at or near the ceiling for the highest possible score. Nonetheless, overall, the result supports the idea that the geocultural connection fostered a stronger sense of importance for Quaternary geoheritage sites, to the extent that they deserve protection.

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Table 6 Quaternary Geoheritage Conservation Priority- DiD analysis by Expertise Level. p-values for DiD coefficients are represented in parentheses.

	Specialist	Non-Specialist
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DiD coefficient: Post-Video Survey (p-value)	0.227 (<0.001)	0.517 (<0.001)
DiD coefficient: Three-months-after Survey (p-value)	0.197 (<0.001)	0.308 (<0.001)

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4.3.4.5 Overall implications: Quaternary Geoheritage

820 These results demonstrate the overall success of using videos to communicate information about Quaternary geoheritage sites, as they effectively enhanced viewers' perceived knowledge of Quaternary science and fostered a heightened sense of the sites' significance for conservation. This result, however, should be tested in the future with participants with a lower interest in nature conservation. At the population level, the study revealed limited increases in interest in learning about Quaternary geoheritage sites, particularly over the long term, despite an overall reported improvement in interest toward these sites. The degree of interest generated by the video may not have been substantial enough to translate into sustained motivation for further learning.

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When comparing the two videos, the treatment video emerged as more effective in impacting its audience in the longer-term. With a singular focus, the control video served as a better education resource immediately after watching, with larger gains in the audiences' sense of knowledge on the subject and score in the quiz. The sense of knowledge was continuously better for the control group, even in the follow up survey. However, in all other aspects, the treatment video provided markedly better outcomes in the longer-term. For specialists, it served as a better tool to identify Quaternary sites, and for non-specialists to raise their interest and sense of need for the protection of these sites. These results, combined with the findings from the previous sections may suggest that the geocultural context in the treatment video enable the audience to better engage with the materials and retain memory of its content. Consequently, the geocultural context provided a positive influence on interpreting and promoting Quaternary geoheritage sites among the study participants.

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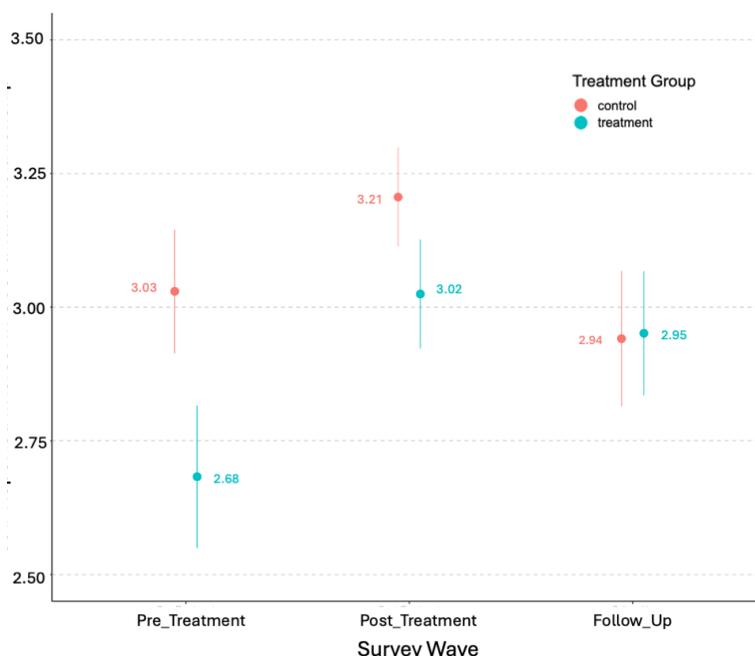
4.3.5 Statistical Analysis: Geocultural Relationship

4.3.5.1 Self-Reported Interest in Relationship between Quaternary Geology and Archaeology

840

Similar to the self-reported level of interest in Quaternary geoheritage (see 4.3.4.1 above), this question asked how interested the participants are to learn about Quaternary geoheritage sites on a five-point scale from 0 to 4. The level of interest that participants reported in the geocultural relationship between Quaternary geology and archaeology saw a small but statistically significant (t-test $p = 0.028$) increase in the post-video wave, followed by mean reversion which returned the results for the respondents overall to a baseline statistically indistinguishable from the first wave results (t-test $p = 0.230$) (Fig. 8).

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850

Figure 8 Geocultural Relationship Interest

Difference-in-differences analysis, however, revealed that the treatment group had significantly different results from the control group for this question – reporting significantly higher increases in their levels of interest than the control group both in the post-video (DiD coefficient = 0.165, $p < 0.001$) and in the follow-up survey (DiD coefficient = 0.357, $p < 0.001$). This effect was stronger in the follow-up survey, with those in the treatment group sustaining their increased level of interest at the three-month point to a notably higher degree than those in the control group. This corresponds well with the fact that the mean of the control group in the follow-up survey was lower than that reported pre-treatment. Moreover, this result suggests that the treatment material was effective in increasing respondents’ interest in the geocultural relationship both in the short- and the medium-term.

Dividing the respondents into specialists and non-specialists and carrying out difference-in-differences analyses on both groups (Table 7) showed that the difference in effect size between treatment and control groups was significantly larger among non-specialists than among specialists. This was sustained in both the post-video and follow-up surveys, with the positive relative effect for the treatment group being seen in all groups but being at its strongest in non-specialist respondents in the follow-up wave. This finding supports the idea that the geocultural context in the treatment material was effective in raising respondents’ interest in the geocultural relationship over a longer term. The gain in the interest, especially of the non-specialist population, in this relationship helps substantiate the claims made in the literature that the geocultural context helps expand the reach of Quaternary geoheritage sites.

Table 7 Geocultural Relationship Interest- DiD Analysis by Expertise Level. p-values for DiD coefficients are represented in parentheses.

875

	Specialist	Non-Specialist
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DiD coefficient: Post-Video Survey (p-value)	0.067 (<0.001)	0.193 (<0.001)
DiD coefficient: Three-months-after Survey (p-value)	0.167 (<0.001)	0.562 (<0.001)

4.3.5.2 Self-Reported Knowledge in Relationship between Quaternary Geology and Archaeology

880 This question asked the participants how much they know about the relationship between Quaternary geology
and archaeology, on a five-point scale. The study found a statistically significant increase in respondents' self-
reported knowledge in the post-video survey (t-test $p < 0.001$). Surprisingly, the mean difference was larger in
the follow-up survey, with statistically significant (t-test $p < 0.001$) outcome, indicating that the participants'
sense of understanding improved three months after watching the video, more so than immediately after
watching the video (Fig. 9). However, it should be noted that the reported scores are generally very low here,
885 with the mean not going over 2, which is the option that describes the extent of knowledge as "Not very much".

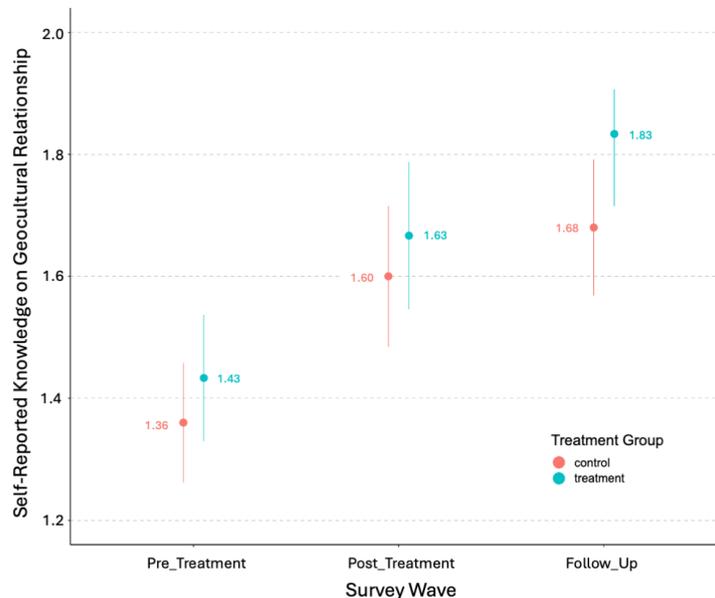


Figure 9 Geocultural Knowledge Scores

890 Difference-in-differences analysis of the two treatment groups revealed a marginal, yet statistically significant
negative effect to being in the treatment group, immediately after watching the video (DiD coefficient = -0.007,
 $p < 0.001$). This effect was reversed in the follow-up survey, in which the treatment group showed larger effects
(DiD coefficient = 0.080, $p < 0.001$). Overall, this result shows a rather limited level of success in the extent to
which the video could make the participants feel more knowledgeable about the geocultural connections (DiD
895 coefficient = 0.037, $p < 0.001$). The larger positive long-term effect towards the treatment group, however,



indicate that the direct mention of such connections did enable the participants to remember about them in the longer-term.

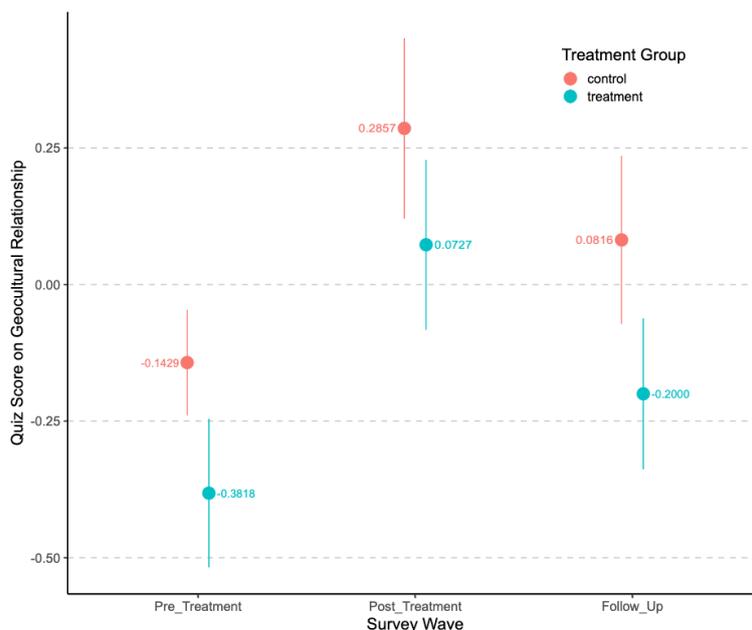
900 The negative results among treatment group members in the post-video survey were led primarily by specialist respondents (Table 8). In the post-video survey, while the non-specialists in the treatment group reported a gain in their knowledge on the geocultural connections than the control group, the divided analysis shows that the lower comparative uplift by the specialists led to the overall worse performance by the treatment group. On the other hand, the better performance of the treatment group is derived entirely by the degree of knowledge retained by the non-specialists. These contrasting results may indicate that the geocultural context included in 905 the treatment video had different effects for the specialists and the non-specialists. For the non-specialists, the geocultural context seems to have been comprehensible, and memorable enough to retain the knowledge after 3-months. For specialists however, the inclusion of this content did not seem to help their knowledge, perhaps as they could recognise its complexity.

910 **Table 8 Geocultural Knowledge - DiD by Expertise Level. p-values for DiD coefficients are represented in parentheses.**

	Specialist	Non-Specialist
DiD coefficient: Post Video Survey (p-value)	-0.091 (<0.001)	0.011 (<0.001)
DiD coefficient: Three-months-after Survey (p-value)	0 (<0.001)	0.135 (<0.001)

915 4.3.5.3 Quiz Scores on Relationship between Quaternary Geology and Archaeology

920 This question was asked to test the subject’s understanding of the geocultural connections by making them select correct examples of relationships between Quaternary geology and archaeology in southeast Arabia. Of the seven choices given, three were correct and four were incorrect. As with the photo identification quiz on Quaternary geoheritage sites shown in 4.3.4.3, the results for this quiz were calculated by subtracting the number of wrong answers selected by each respondent from the number of correct answers they selected, in order to avoid the figures being skewed by respondents who selected a large number of answers. In this case, it is important to note that the resulting scores were extremely low overall, with the means in all waves hovering around zero (Fig. 10). The responses seem to suggest that either the question was too difficult, or most respondents did not understand this aspect of the material presented. Despite the low overall scores, however, 925 there was a statistically significant improvement in the post-video survey (t -test $p = 0.0014$). The mean scores in the follow-up survey were also improved from the original quiz, but this is not statistically significant at the 95% confidence level (t -test $p = 0.1086$). The improvement by the control group in this quiz was rather surprising, but it may indicate how the audience could connect the scientific contents of the video with their implications for the regional archaeology, when prompted to do so. This ability, as well as the fact that they 930 were asked questions about these connections in each survey could be an explanation for the control group answering “connection between Quaternary geoheritage and culture/archaeology” as the part of the video that left an impression for them.



935

Figure 10 Geocultural Quiz Scores

The difference-in-differences analysis suggests that overall, the treatment group saw a marginally smaller improvement than the control group in this quiz (DiD coefficient = -0.008, $p < 0.001$). Compared to the control group, the treatment group had slightly more improvement in the post-video survey (DiD coefficient = 0.026, $p < 0.001$), and slightly less improvement in the follow-up survey (DiD coefficient = -0.043, $p < 0.001$). However, these effect sizes are extremely small and while they are statistically significant, the actual degree of difference they represent does not seem meaningful.

Dividing respondents into specialists and non-specialists (Table 9) enables an observation of quite different results for the two groups. Among specialists, the treatment group had slightly worse performance in the quiz compared to the control group, while among non-specialists, the treatment group had slightly better performance (although the difference between treatment and control groups largely disappeared by the follow-up survey among non-specialists). This is the opposite of the outcome of the result of the quiz on detecting Quaternary geoheritage sites, in which the specialists in the treatment group led the overall improvement of the treatment group over the control group in the follow-up survey. On one hand, it could be an indication that the elements remembered by the specialists and non-specialists were slightly different after watching the treatment video. Perhaps the non-specialists remembered more about the geocultural relationship, a topic that they are more familiar with, rather than the Quaternary science elements of the video. On the other hand, it may be the case that this aspect of the video was rather confusing for specialists with previous knowledge. However, it remains unclear why the specialists in the treatment group performed worse in answering these questions, given the information provided in the video and their previous knowledge on geosciences.

Table 9 Geocultural Quiz- DiD Analysis by Expertise Level. p-values for DiD coefficients are represented in parentheses.

	Specialist	Non-Specialist
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DiD coefficient: Post Video Survey (p-value)	-0.098 (<0.001)	0.124 (<0.001)
DiD coefficient: Three-months-after Survey (p-value)	-0.133 (<0.001)	0.038 (<0.001)

960 **4.3.5.4 Overall implications: Geocultural Relationship**

Overall, these findings highlight that communicating about Quaternary geoheritage sites primarily enhances the audience's recognition of the geocultural relationship, rather than fostering a sustained interest in the topic, particularly in the longer-term. Additionally, despite the perceived increase in knowledge post-viewing, participants reported a relatively low level of understanding even after watching the videos. Assessing the impact on knowledge improvement via the quiz was challenging due to the overall low scores, potentially stemming from factors such as confusion or the complexity of the question.

965 Comparing the two videos, the treatment video, with its emphasis on the geocultural aspect, appeared to stimulate greater interest in the subject, particularly among non-specialists, suggesting that the geocultural context effectively engages audiences in communicating Quaternary geoheritage sites. On the other hand, this gain in interest by the treatment group did not translate to a better improvement in the quiz. The treatment group, particularly the specialists, fared worse than the control group in all three waves, as well as in terms of overall improvement in the score. Given the treatment group's enhanced memory retention observed in other parts of the study, it seems likely that the geocultural context stimulated curiosity of its viewers. However, this curiosity did not directly lead to enhancing participants' factual understanding. As an outreach tool, however, these findings underscore the effectiveness of incorporating geocultural context as a tool in introducing Quaternary geoheritage sites to the general public.

980

5 Conclusions

This study aimed to investigate the effectiveness of using educational videos and the geocultural context to introduce the significance of Quaternary geoheritage sites in southeast Arabia. Through a comprehensive three-phase approach involving focus groups to determine the video contents, video production, and an online experiment, the study assessed the impact of two distinct videos—one highlighting the geocultural context and the other focusing solely on Quaternary science—on participants' knowledge, interest, and perception of Quaternary geoheritage sites.

990 The findings reveal several key insights into effective science communication strategies and the role of geocultural connections in fostering audience engagement with Quaternary geoheritage. The input gathered from relevant local specialists during focus group discussions emphasised the significance of visual appeal, narrative coherence, and culturally relevant storytelling in capturing audience interest and establishing a meaningful connection with the subject matter. These insights informed the development of clear and easily comprehensible videos.

The experimental comparison of the two videos provided valuable insights into their effectiveness in conveying key messages and engaging the audience. Both videos resulted in significant improvements in participants' knowledge and attitude towards protecting Quaternary geoheritage sites. The benefit of incorporating



1000 geocultural connections could be seen in improved longer-term scores for the quiz and levels of interest. The
geocultural video also enhanced participants' interest and understanding of the cultural significance of
Quaternary geoheritage, particularly among non-specialists. Methodologically, this study showed the
importance of considering longer-term effects of interventions in geoscience communication studies and
1005 demonstrated marked differences in learning experiences between those with and without previous knowledge
in the field.

The study identifies two primary advantages of integrating geocultural context into science communication
efforts for Quaternary geoheritage sites in southeast Arabia. First, the inclusion of geocultural context enhanced
the videos' engagement and appeal, particularly for non-specialist audiences. Second, while not as immediately
1010 effective as a teaching resource, the geocultural context appeared to improve viewers' retention of the video
contents and fostered a greater need to protect Quaternary geoheritage sites.

Limitations of this study includes the rather small sample size and the pro-nature conservation attitude of the
participants. Future studies in different contexts could help understand whether these benefits are applicable in
1015 different social, cultural, and/or geographical context. Furthermore, exploring the applicability of geocultural
connections to promote awareness and conservation of geoheritage sites more broadly represents an important
avenue for future investigation.

In conclusion, this study advances understanding of how integrating geocultural connections can enhance
1020 science communication efforts aimed at promoting awareness and conservation of Quaternary geoheritage. By
leveraging the cultural relevance of these sites in communication strategies, Quaternary scientists and
geoheritage practitioners can enhance audience engagement, deepen understanding, and inspire longer-term
changes in the attitude towards the protection of Quaternary geoheritage sites. These insights offer valuable
guidance for refining communication strategies for complex scientific concepts and fostering public engagement
1025 with Quaternary science initiatives.

Author contributions

1030 Conceptualisation, K.S., H.V.; Data curation, K.S. H.A.R., R.A.F.; Formal analysis, K.S., R.A.F.; Funding acquisition, K.S.;
Investigation, K.S., H.A.R., R.A.F.; Methodology, K.S., R.A.F., H.V., A.G.P.; Project administration, K.S., H.A.R.;
Software, R.A.F, K.S.; Supervision, H.V., A.G.P.; Validation, K.S., R.A.F; Visualisation, K.S., R.A.F.; Writing—original
draft, K.S.; Writing—review and editing, K.S., R.A.F., H.V., A.G.P. All authors have read and agreed to the
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Ethics statement

1040 This study was approved by the Central University Research Ethics Committee (CUREC) at the University of
Oxford to have followed the research protocols set out by the committee with the approval references: SOGE
C1A 22 252 and SOGE C1A 23 15.

Conflicts of Interest

The authors declare no conflict of interest regarding this research project.

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