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# Revisiting education and training programs: Geoarchaeology as a driver of interdisciplinary reasoning

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A core problem of contemporary society is rooted in the educational system and the divides created between the humanities and sciences that have prevented integrated reasoning. This problem affects society at large and has severely impacted the mindset of leadership, precluding in-depth debates involving citizens that lack an understanding of the basic notions and concepts that drive other agencies. Thus, the Lisbon Declaration, approved at the European Humanities Conference based on proposals by UNESCO, CIPSH, and FCT, calls for the integrated teaching of humanities and sciences units at all levels of education, including the doctoral level. This chapter discusses the potential contribution of geoarchaeology towards that aim, as this discipline sits at the heart of the humanities-sciences interaction, thus bridging science methods with human behavior. Geoarchaeology is one of the most important archaeological research methods that offers unprecedented levels of integration between disciplines and geoarchaeological research. It is a good example of how geosciences can contribute towards re-thinking education, in terms of research-based education: learning to research, learning that research on the earth and humans is by nature interdisciplinary, learning to design answerable questions, learning to frame scientific analysis within wider meanings and prospects, and fostering an understanding of the truth and the criteria for truth. This topic is a unique bridge between both human and earth sciences and between science and human behavior, which play pivotal roles in communicating and educating about sustainability. The multidisciplinary dimensions of geoarchaeological approaches have encouraged continuous development and innovation of methods and approaches that have provided new possibilities for explorations in geosciences, research on earth and humans, learning to design answerable questions, and fostering an understanding of truth and the criteria for truth. This text discusses two examples: pigment analysis and micromorphology. Pigment analysis relates scientific methods with rock and mobile art, and also involves experimentation in the making of the art itself, which is a powerful didactic tool, thus linking science with daily observed realities and related cultural traits.

Micromorphology is a geoarchaeological methodology currently applied to research, which provides a unique insight into the interdisciplinarity and multidisciplinary relationships associated with humans and society. Despite the complexity of this approach, it provides easily understood information on various segments of society; e.g., soil formation, thus making it one of the most effective tools in the Earth Sciences sector contributing to sustainability and related to daily behavior practices.

#### KEYWORDS

geoarchaeology, education, science, humanities, interdisciplinarity

## 1 Education as a domain of research and co-construction of knowledge

A core problem of contemporary society is rooted in the educational system and the divides created between the humanities and sciences that have prevented integrated reasoning. This problem affects society at large and has severely impacted the mindset of leadership, precluding in-depth debate involving citizens that lack an understanding of the basic notions and concepts that drive other agencies. One major dimension of this impact concerns the understanding of drivers that condition options to make coherent, sustainable, and effective decisions regarding the management of territories as a fundamental dimension of governance.

While sciences, particularly earth sciences, allow the characterization of a territory and its material features, human societies do not make decisions based on information provided by natural sciences but rather on their perceptions of those territories; i.e., landscapes combining observation, scientific and other information, cultural background assessment, and experience. Education and training are key elements in the building of shared landscapes; i.e., shared convergent perceptions of territories, as words not only condition the growth of the ideas to consider but also structure the hierarchy of possible ideas and, moreover, the vision that will guide actions (Derrida and Duarte, 1967).

For example, the acronym “STEM” (Science, Technology, Engineering, Mathematics) expresses the technological approach to solutions and the exclusion of the humanities, especially when facing dilemmas or contradictions. Even when this acronym is sometimes transmuted to “STEAM” (Sousa and Pilecki, 2013), with “A” representing Arts (or creativity), the dimension of the humanities is still left out, in a possibly unconscious but nevertheless effective way to foster a monolithic understanding of sustainability (which values economic growth and environmental protection but does not understand the anguish and human divisions).

As it brings together geoscience methods to assess the contexts of human behavior, geoarchaeology is, along with some of its methods, a relevant avenue for fostering a bridge between science and humanities; i.e., interdisciplinarity

reasoning in academic research as well as an interdisciplinary framework for society, which is a precondition for transdisciplinary research (Von Wehrden et al., 2019).

An education “amputated” of the humanities reduces the possibilities for the articulation of phenomena and affects the understanding of territory opportunities and constraints, as well as the possibilities for intervention within these factors. The importance of the humanities in this field lies in the fact that they integrate the knowledge conveyed by natural and social sciences (and their analytical and predictive capacities) into a broader multidisciplinary approach that involves archaeology (and the didactics of tangibility and reasoning-related technologies and techniques, which are a crucial driver of sustainability strategies), anthropology (and understanding of the cultural processes and mechanisms of convergence or social fission, a crucial driver to foresee potential social disruption), history (as a rational construction of the common past and not a mere collection of dividing memories, which is crucial for the assessment of climate change), geography (and the positioning of actors in relation to spaces, distances, processes and actions, which is crucial to foresee the potential impacts on border design), literature (constructing narratives and perceptions, which is crucial for translating interdisciplinarity into integrated reasoning in society at large), psychology (of individuals and groups in their cultural contexts, which is crucial for conflict management), and other approaches framed in the archipelago of philosophy through communication, education, and training (Castells, 2010; Scheunemann and Oosterbeek, 2012; Crowley, 2016).

However, citizenship education and critical reasoning cannot be achieved through disciplinary intellectual training alone. The development of intelligence requires motricity and interactions between phenomena, stimulating the connections between the muscles and the brain, a process that has been countered by the increasing digitization of all procedures (Oosterbeek, 2014).

However, in addition to research on these complex systems, it remains to be seen how to promote tangible learning and reasoning experiences (which are crucial for developing critical reasoning and unalienated citizens that are the basis of citizenship and dynamic and non-despotic societies), when any

child's experience is that a much smaller effort using digital resources can lead to the satisfaction of perceived needs (Vasile, 2012)?

While training, outside of full education, leads to superficial and non-flexible landscapes and language, by itself, constructs narratives of segregated and encrypted landscapes, education combines training and language for the critical prediction and decryption of meanings. Therefore, education is one of the main instruments of globalization. However, the strength of education is also its main weakness: the empowerment of individuals through education is a process of abstraction, which allows them to create non-existent entities that can be transformed and adapted to completely new contexts (innovation is one such example). In doing so, education breaks the perception of the equality of human beings and their environment by demonstrating the human capacity to overcome material constraints, potentially creating anthropocentric landscapes that overcome ethnocentric approaches but, paradoxically, allow for massive environmental destruction by "freeing" humans from any constraints. Thus, reconnecting human agency and impact (the focus of archaeological research) to territorial features within their diachronic processes and balances (the focus of geosciences) is a major need in contemporary digital societies.

Digitalization is transforming gesture requirements related to knowledge sequences and their achievements (Carr, 2011): fewer movements are needed to achieve similar results, and the same movements (e.g., pressing a key) lead to very different results (e.g., pressing a key at an ATM, car park, or beverage distribution machine). This decrease in gesture diversity tends to reduce brain stimulation, interrupting the causal link and the structuring of complex sequences of reasoning. Particularly in the phases of intelligence evolution that precede formalization, especially when mental operations rely on concrete objects (Piaget, 1954), a primary question is: will human beings, if alienated from their involvement in causal sequences through concrete and tangible objects, be later able to fully develop abstract knowledge? For example: since, from childhood, the link between gesture and concrete reasoning required for different tasks (e.g., holding a pencil to write a text or doing basic arithmetic calculations) is largely abandoned due to the early use of computers, which automatically correct spelling and make very fast calculations, it remains unknown if the subsequent construction of poetic or algebraic mentalities continues to be accessible.

Geoarchaeology may be ideally placed at the core of pedagogic strategies to face this loss of awareness. By introducing geoarchaeological methods and experiences in the education process in disciplines such as natural sciences, history, geography, and ecology, schools may not only foster an interdisciplinary framework of reasoning but also promote a research-oriented understanding of life and a valorization of science.

A school is essentially a space for the socialization of knowledge, experimentation with the dynamics of interpersonal relationships, and, above all, learning the dialectical relationship between rigor and flexibility. Or, in other words, a space for the introduction and subsequent cognitive deepening of the integrated dynamics (ecosystem) of reality, which can eventually be disintegrated by human perceptions; that is, by culture (Palacio-Quintin, 1990). There is a first relationship between school, science, and culture (Goslin, 1965), in which culture is the set of extra-somatic behaviors of humans organized in society and school is one of its manifestations (the choice of a particular form of socialization, experimentation, and learning) and only finds its meaning if it is aligned within the cultural matrix (Gauthier, 2006). Efforts to segregate school from the cultural universe, imposing misaligned discourses of the concrete sociocultural fabric, are halfway to the failure of its mission. However, efforts to limit the school to its immediate sociocultural context, imposing misaligned ethnocentric narratives of the basic notion of the unity of humanity, is the other halfway point to the failure of its mission. This mission is, or should be, quite simple: preparing for uncertainty, reducing anxiety and anguish, and promoting critical and forward-looking reflection (Chatel, 2001). Science is also part of culture, as it is either part of the fundamental reasoning of a society that recognizes the value of the scientific methods and probability, or will tend to be perceived as an alien culture itself, namely because the fundamental reasoning of science lies in analytics, while the fundamental critical reasoning of people lies in experience (Dagnall et al., 2019). This is the origin of most contemporary anti-science discourses and movements. Having separated the teaching of science (what exists and how it may be monitored and transformed) from the teaching of humanities (what is existence and why it should be transformed), education has paved the road for expelling science from culture, attempting to consider it as totally external. However, it is not, as it is an expression of cultural globalization. Denying this role undermines and weakens the scope of science.

Understanding culture as the totality of the products of human action and its communities, as well as understanding education as the totality of cognitive interactions that each of us establishes in society, are starting points for action plans that cannot admit the compartmentalization of spaces and are, therefore, oriented towards a vital logic (aligned with life) in the management of the world as the "substrate and scene where one develops the game of our aptitude", as Kant (1802) wrote. That is why the immersion of the school in the territory is so important (Champollion, 2015) and, why geoarchaeology is the best avenue to address this immersion.

A dramatic consequence of the growing division between sciences and humanities has been the global weakening of both, leading to a pragmatic empire of technological solutions deprived of global meaning and reasoning (Böhme and Stehr, 1986;

Oosterbeek, 2011). Several recurrently used words illustrate this dangerous division, including “solutions” (ignoring contradictions and dilemmas), “technology” (ignoring purpose), “memory” (ignoring history), “democracy” (ignoring consciousness and alienation), “theory” (ignoring praxis), or “education” (ignoring content—Oosterbeek, 1999).

The consequences are found in all spheres of activity, and certainly in the main global challenges for which non-integrated solutions are repeatedly experienced with limited results (as the pandemic has evidenced), whether they relate to climate change (oscillating between denial of change and over-evaluation of anthropic impact), to migration (without associating them with the nature of existing borders), to identities (reducing ethnocentric cultural conflicts to multilateral dialogue, without facing the challenges of building a united humanity for the first time), to an understanding of the past (in the absence of an effort to build a comprehensive global human past, rather than a collection of fragmented local and regional stories), or others.

Globally, the main consequence has been the lack of an understanding of cultural complexity, seeking the same solutions, rooted in social engineering and technology, for different types of inequality, exclusion, and conflict. Part of this misunderstanding has a major impact on education and training strategies, largely still oriented toward a 20<sup>th</sup>-century profile of new jobs created in relation to new economic activities and to a decolonization agenda. While these remain relevant aspects, the redefinition of socio-cultural processes in the previous North-South division (with a much more complex set of intra-regional cleavages and the emergence of cultural divides and disturbances—Hellier, 2012) must be considered, including the current nature of the economic process (which no longer generates a sufficient number of jobs related to economic growth mechanisms) and the cognitive implications of the digital age (decreased use of muscles and, in particular, of the brain, to achieve different goals).

This is the overall context of the Lisbon Declaration, approved at the European Humanities Conference based on a proposal from UNESCO, CIPSH, and FCT, which called for including curricular units for the integrated teaching of humanities and sciences at all levels of education, including the doctoral level (<https://europeanhumanities2021.pt/lisbon-declaration-and-outcome-document/>). The Lisbon Declaration emphasized the role of the school in establishing (or not) this disciplinary segregation. However, this difficulty will not be overcome without understanding that educational spaces are not only classrooms.

## 2 Geoarchaeology and interdisciplinary education

Geoarchaeology is a critical field of research that combines archaeology and geosciences, as described by Butzer, 1986 and

Gladfelter, 1981. It is at the heart of the humanities-sciences interaction, thus bridging science methods with human behavior.

Geoarchaeology is a cluster of archaeological research methods that offer unprecedented levels of integration between disciplines (Gladfelter, 1981). It is a good example of how geosciences can contribute to re-thinking education, in terms of research-based education: learning to research and learning that research on earth and humans is by nature interdisciplinary, in addition to learning to design answerable questions, learning to frame scientific analysis within wider meanings and prospects, and fostering an understanding of truth and its criteria.

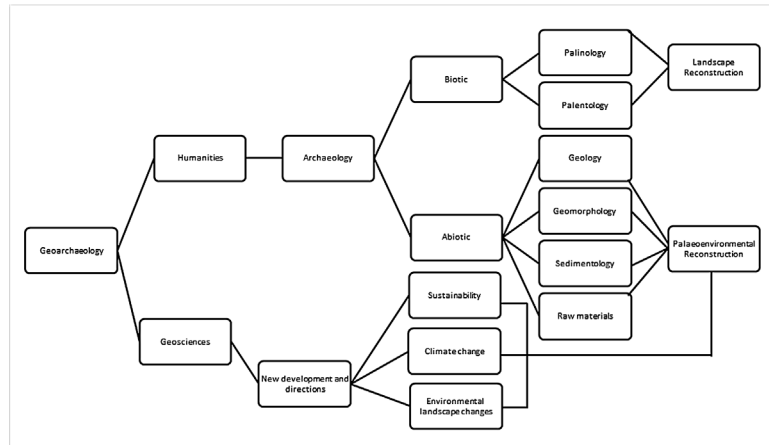
While geoarchaeology, is a unique bridge between human and earth sciences, it also plays a pivotal role in bridging science and an understanding of human behavior to communicate and educate about sustainability. The multidisciplinary dimensions of geoarchaeological approaches have encouraged the continuous development and innovation of methods and approaches that have provided new possibilities for explorations in geosciences, including research on earth and humans. This new development and directions are linked to various discussions such as sustainability, environmental changes, human-environment interaction, environmental landscape, and effects of climate change, which are all part of this new interdisciplinary dimension (Gladfelter, 1981; Butzer, 1986, 2011; Angelucci, 2022).

To better understand archaeological contexts, geoarchaeology considers both biotic and abiotic contexts (Figure 1). The former focuses on landscape reconstruction, paleoenvironmental reconstruction, anthropology, and paleontology, while the latter considers aspects of geology, geomorphology, sedimentology, site formation, modification processes, and georesources (Figure 1). These contexts are naturally composed of several fields and sub-fields that create interlinks and correlations between human and science interactions. An example is the chapter of geoarchaeology that aims to educate on the study of cultural heritage, which directly relates to humanities studies (Angelucci, 2022).

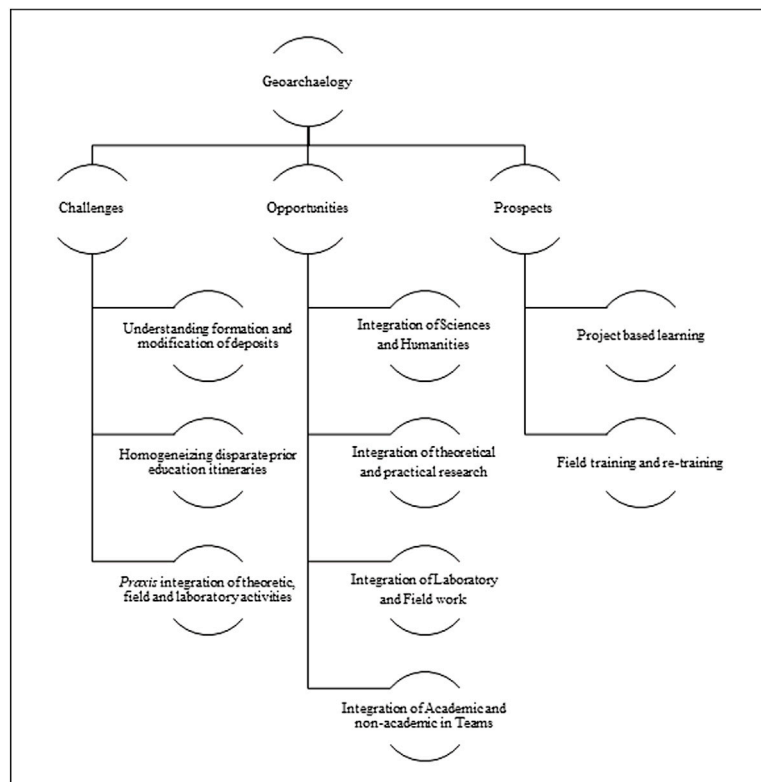
In recent years, geoarchaeology has shifted focus and directions to the humanities, bridging the gap between the traditional field of studies, the scientific and humanistic, to achieve the current trends and development in research (Angelucci, 2022). The integration of geoarchaeology into secondary and tertiary curricula will provide education with a unique framework for cross-disciplinary research and training.

### 2.1 Challenges, opportunities, and prospects

Several challenges are embedded in the research process of geoarchaeology, ranging from the understanding of cross-disciplinary themes (e.g., site formation processes) to the



**FIGURE 1**  
Interdisciplinarity in geoarchaeology.



**Geoarchaeology and its interdisciplinarity**

**FIGURE 2**  
Challenges, opportunities, and prospects in Geoarchaeology.

training of specific skills or the technical know-how to address geoarchaeological-related research questions and problems during investigations (Figure 2). Moreover, as a field of science that engages students from both sciences and humanities, it provides a didactic experience particularly suited for contemporary needs, even if the transfer of geoarchaeological knowledge into such a diverse range of academic backgrounds is often a herculean task.

There has been a growing emphasis on the theoretical framework in acquiring geoarchaeological knowledge. Beyond the combination of methodological approaches in fieldwork and the laboratory, geoarchaeology is relevant for assessing georesources and human adaptations (e.g., assessing organic artificial enrichment of soils or recording biomass fluctuations) (Kluiving et al., 2019).

In prehistoric archaeology, students must consider at some level geoarchaeological approaches in fields like archaeometry, sedimentology, and paleoenvironmental reconstruction. Moreover, in the context of human adaptations, geoarchaeological methods provide an integrated method of addressing themes like climate change and dwelling strategies, which is relevant for understanding contemporary problems, such as sustainability (Brown et al., 2011; Roque et al., 2020).

Thus, geoarchaeological research is also a good platform for training, re-training, and methodological site-based innovation within humanities-sciences-related research. It encompasses a flexible three-legged approach of the theoretical-field-laboratory praxis (Figure 2) that can result in the full development and integration of those involved in the project investigations. Well-spent time focusing on the theoretical problems, transferring this knowledge to the field, and first-hand laboratory experiences contribute to a multidisciplinary mindset in which the disciplines are both the root and bridge for the framework of education and training. A major prospect is a project-based learning process that impacts students, scholars, and researchers through practical training based on field activities.

### 3 The praxis of knowledge: experimentation and analytics

To better understand ways of integrating geoarchaeological research with education, this text discusses two examples: pigment analysis and micromorphology. Pigment analysis relates science methods to rock and mobile art and also involves experimentation in the making of the art itself, which is a powerful didactic tool, thus linking science to daily observed realities and related cultural traits. Micromorphology allows better assessment of site formation and modification, mostly related to anthropic activity and other disturbance geo or bio agents, thus bridging field and laboratory work with the empirical direct observation of sedimentary deposits to increase the

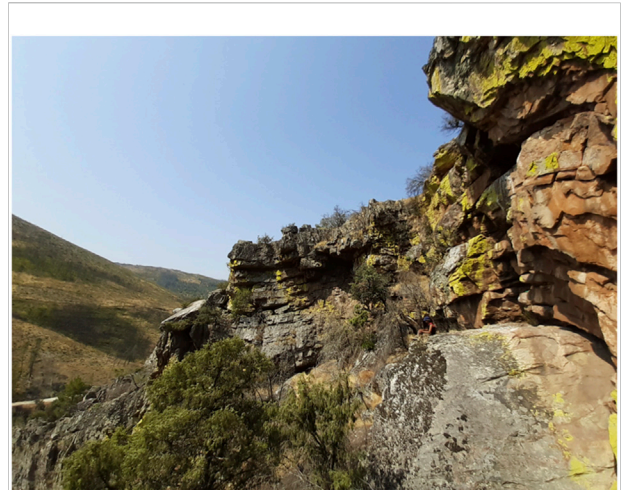


FIGURE 3  
Field training and science education.

understanding of the notion of scale when applied to material evidence in space and time.

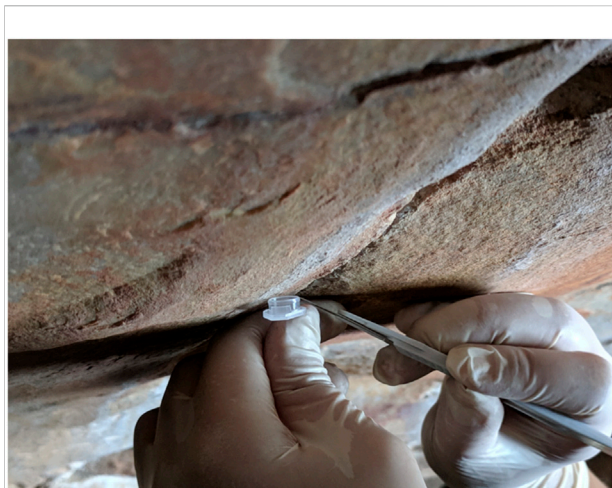
#### 3.1 Pigment analysis

The use of key sites to foster the relationship between humanities and geosciences is crucial. As such, the prehistoric rock art shelter of Pego da Rainha in Mação is used as an example of fostering training in geoarchaeology and education for sciences through a multidisciplinary approach that builds from questions structured from the humanities sector, concerning the choices of raw materials, their manipulation, the sequence of procedures, etc. (Figure 3).

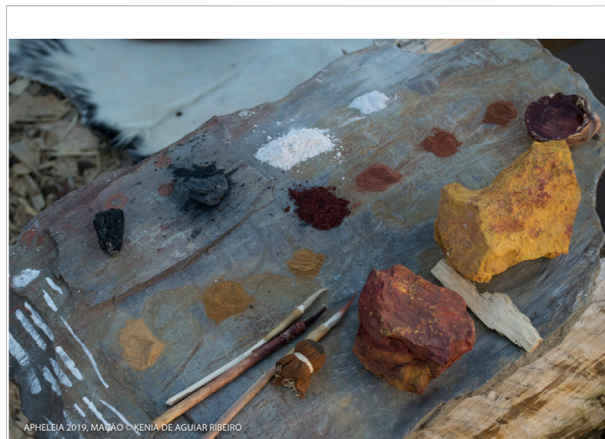
Red pigmentation (and its derivatives) is the most common painting material used in prehistoric painted rock art in the Iberian Peninsula (if not the world). These red pigments may have been selected due to the relative abundance and availability of raw materials (Thomas, 1980; Fuller, 1988; Mas et al., 2013) or may have been associated with color symbolism (Wreschner 1980; Michaelsen et al., 2000; Zilhão, 2007; Zilhão et al., 2010; Peresani et al., 2013).

Pego da Rainha rock shelters I and II (located in Mação, Portugal) contain a small group of schematic motifs. These figures (unlike their counterparts elsewhere) are not superimposed by later painted figures. The iconographic repertoire includes mainly linear figures, digits, and semicircular geometric forms (Oosterbeek, 2002; Martins, 2013), although an anthropomorphic figure was recently found (Pillai, 2019).

The Pego da Rainha shelter is one of the few painted shelters of schematic art in central Portugal, an area that is diverse both from a geological and geomorphological point of view as well as



**FIGURE 4**  
Pigment extraction.



**FIGURE 5**  
Painting materials and preparation.

from the point of view of human settlement and occupation of the territory over thousands of years (Oosterbeek et al., 2010). The explanation of the paintings implies not only the assessment of the pigments but also of the geological and geomorphological settings.

The shelter is located in a quartzitic ridge structured NW-SE, which cuts across the Tagus valley that runs NE-SW. While other shelters with paintings have been identified along the quartzitic ridge, Pego da Rainha is located in the heart of the Tagus Valley Rock Art Complex, an area whose central core includes around 7,000 engravings over 40 km (Garcês, 2019). These engravings correspond to different moments over 20,000 years, mainly concentrated in the maximum glacial upper Paleolithic hunters, the Holocene late hunter-gatherers at the dawn of pastoralism, and the Bronze Age. As this shelter is the only painted site amidst a large group of engraved sites, its importance in the understanding of the symbolic dynamics of prehistoric communities increases significantly. It also corresponds to the moment when these communities adopted patterns of living including agriculture, and the herding and domestication of animals a fundamental moment in the history of humanity.

Our research included technological processes to determine which materials (e.g., hematite, goethite) were used in subsequent pigment recipes in Pego da Rainha. Pigments from several rock painting panels (Figure 4) were analyzed using micro-Raman spectroscopy and X-ray microfluorescence (Gomes et al., 2013).

This allows us to also explain to students that Raman spectroscopy is a high-resolution technique that can provide chemical and structural information of any material or organic or inorganic compound within seconds, thus allowing its rapid identification. Raman analysis is based on monochromatic light of a certain frequency that behaves differently when applied to different materials. Light that maintains the same

frequency as the incident light does not reveal any information about the material and is called Rayleigh scattering; however, the light that changes reveals the molecular composition of the material and is known as Raman scattering (Gomes, 2020). X-ray fluorescence spectrometry is used to perform qualitative elemental analysis to characterize and identify the chemical composition of pigments (Gomes, 2020).

Inorganic iron-rich red pigmentation appears to have been the preferred substance used for prehistoric paintings and is found in many rock art areas worldwide. Depending on where the sources of the pigments were extracted, the natural chemical processes produced many different shades of red. The results of archaeometry studies demonstrate that pigments *per se* incorporate many different minerals. Whether or not the pigment color was specifically chosen for its symbolic qualities is not an issue for this paper, although these qualities cannot be ruled out. One can suggest an association between the technology of pigment (mineral) abstraction, application, and ritual/symbolic activities.

The techniques of pigment production and application from the Pego da Rainha site are not directly correlated to chronology, pictogram style, or, in this case, schematic art (García Arranz et al., 2012). Therefore, pigment extraction and preparation must be in part the result of raw material availability. Other reasons may be associated with color symbolism and meaning (Nash 2008).

In the study of pigments in prehistoric art, the conception of not only several disciplines but also a base of both humanities and sciences increases understanding of the complex phenomenon of prehistoric art.

These studies involve the entire student community from various master's and doctoral-level courses, explaining and disseminating the potential contribution of the methods used in a geoarchaeological study, which is at the heart of the



**FIGURE 6**  
Painting processes.



**FIGURE 7**  
Knapping process.



**FIGURE 8**  
Tool production.



**FIGURE 9**  
Clay production.

humanity-sciences interaction, thus bridging scientific methods and human behavior.

In practical terms, the pigment analysis, as described above, is often complemented by experimental archaeology, including fieldwork and sampling. These activities can be replicated in the pre-university academic framework, where students can easily learn in a simple and attractive manner as described below.

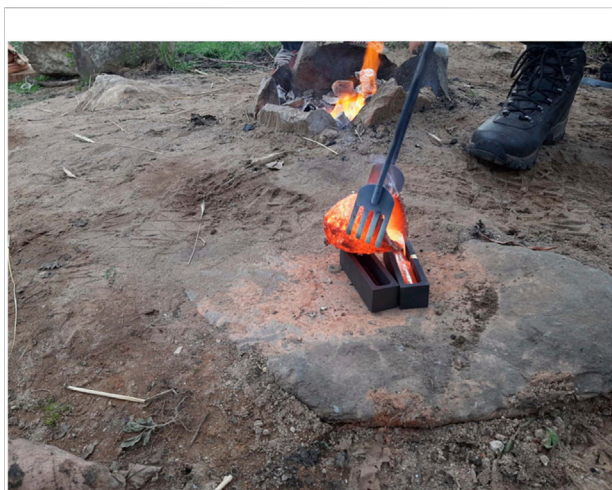
For instance, based on this research, we have conceived two workshops, dedicated respectively to rock painting and to rock engravings (Figures 5, 6). The workshop on paintings would offer a variety of experiences, from the processing of the pigment from minerals to the tools used for painting. The engraving workshop would additionally offer experiences with the use of the tools for training. These workshops encourage creative development as well as the notions of geology and chemistry. They also offer a journey to prehistorical life and its knowledge of chemistry related to paintings and of physics related to engravings.

The study of rock art also extends to the study of raw material procurement and transformation, including the assessment of engraving techniques associated with lithic materials, allowing for an understanding of the complex production processes, related technological and socio-cultural practices, and their changes over time (Inés & Annalisa, 2021). A lithic workshop offers a journey through one of several ways of producing stone tools, through knapping (Figures 7, 8). The participants of this workshop can choose tools that best suit their gestures, as this kind of activity helps to develop gesture coordination.

Another relationship, that between ceramic and rock art, provides opportunities to relate the dimensions of symbolism (as expressed through the convergence of decoration motives), raw materials, and objects (as expressed through the difference in the two contexts).

A workshop on ceramics, spanning clay collection and preparation (Figure 9) to its transformation into utilitarian





**FIGURE 10**  
Melting process.

objects through modeling and firing (Figure 10), promotes creativity, high levels of coordination, and basic knowledge of local geology.

Metals, also used in later stages of rock art production, are a further avenue to approach the relationships between materials, techniques, tools, and economics. In a methodology workshop, three transformations are introduced: smelting, melting, and casting. The techniques to produce several types of molds are demonstrated and performed through reduction, the process of extracting metal. Through melting, the process of alloy formation combining different metals and also the concept of recycling are demonstrated.

In conclusion, these kinds of workshops promote development, creativity, and hand coordination, through increased knowledge of physics, chemistry properties, and processes in learning how geology relates to all spheres of life and why purpose and meaning guide those processes.

### 3.2 Micromorphology

The integration of micromorphology into the earth/geosciences sector in the context of archaeological studies has profoundly increased in the last 3–4 decades (Goldberg and Aldeias, 2016). This method assesses geoarchaeological problems related to paleoenvironmental changes and human activities, distinguishing between natural factors and human influence, determining the dynamics of cultural processes, and identifying primary, secondary, and tertiary cultural deposits.

The application of this method often employs science-driven approaches in addressing site-specific research questions in geosciences studies (Goldberg 1980; Bullock and Murphy

1983; Murphy 1986; Fedoroff et al., 1987; Courty et al., 1989; Douglas 1990; Macphail et al., 1990; Ringrose-Voase and Humphreys 1994; Stoops 2003; Stoops et al., 2010; Stoops 2014). One example is micromorphology, which provides information on not only the sedimentary dynamics and cultural process but also stratigraphic assessment for the detailed environmental reconstruction of human paleolandscapes and also identifies various kinds of domestic and specialized human activities (e.g., trampling, digging, agriculture, and construction) that can be detected in thin-section analyses (Courty et al., 1989; Watez et al., 1990; Goldberg and Macphail, 2006; Angelucci et al., 2009; Miller et al., 2010).

The scope of micromorphology as a discipline in the context of inter-multidisciplinary studies in recent years has broadened greatly with its combined use with other multi-proxy analytical techniques such as magnetic susceptibility, Fourier transform infrared spectrometry (FTIR), and scanning electron microscopy-energy dispersive X-ray analysis (SEM/EDAX), as evidenced in the works of many scholars and researchers within the last 4 decades (Babel 1975; Courty and Roux 1995; Macphail and Goldberg 1995; Macphail and Goldberg, 1995; Crowther 1996; Karkanas et al., 1999; Courty 2001; Canti 2003; Macphail et al., 2003; Schiegl et al., 2003; Schiegl et al., 2004; Shahack-Gross et al., 2004; Shahack-Gross et al., 2005; Goldberg and Macphail, 2006; Berna et al., 2007; Macphail and Crowther, 2007; Karkanas and Goldberg 2008; Berna et al., 2012; Courty et al., 2012; Mentzer and Quade 2012; Mentzer and Quade, 2012; Friesem et al., 2014; Friesem et al., 2014; Karkanas and Van de Moortel 2014; Shahack-Gross et al., 2014; Shillito et al., 2014).

There exist many reasons supporting the use of micromorphology and its basic principles in the context of education. These reasons may be broadly grouped into two main categories: the production of micromorphological analysis reports and data and the use of those results; e.g., by archaeologists, geoscientists, and scientists at large (Goldberg and Aldeias, 2016). The process of production is often very difficult to grasp by non-specialists, as explained by Goldberg and Aldeias, 2016 who suggested a better and more user-friendly approach to illustrate and describe micromorphological data. However, education on the strengths and limitations of micromorphology, which is common in the field of geoarchaeology (Goldberg, 2008), become more useful for the didactics of multidisciplinary inquiries.

A great example of overcoming these challenges and better communicating micromorphological data is its full incorporation into the lectures and laboratory sections of archaeology courses or geosciences-related disciplines even in the pre-university framework. This enables producers to present clearer and more informative data for the users' easy acquaintance with the knowledge being communicated, thus allowing producer-consumer friendly interactions and communications (Goldberg and Aldeias, 2016).

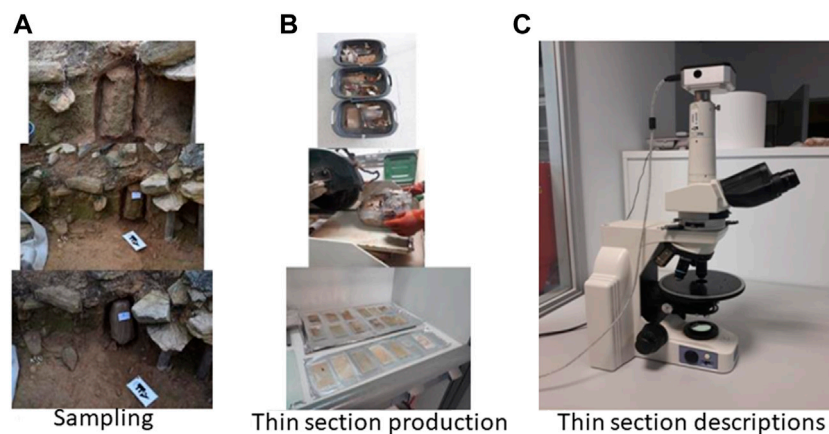


FIGURE 11

Abridged steps of micromorphology analysis: (A) Sampling; (B) Thin section preparation; (C) Thin section descriptions.

In general, three fundamental steps are involved in the processes leading to better communication/presentation of micromorphological results and data applicable to users at the pre-university and even post-university educational levels. These range from field sampling to sample processing and, ultimately, thin section analysis, which encompasses the description of data and its interpretations. In this context, we will demonstrate the steps mentioned above, the kind of results this methodology can provide, and how this method can be used in the pre-university teaching setting, using the example of Anta 1 de vale da Laje, a megalithic monument located in Tomar, Portugal.

The Anta 1 de Vale da Laje site is located 136 km NE of Lisbon, approximately 160 m a.s.l., and on the East bank of the Zêzere River. This affluent area on the northern margin of the Lower Tagus is approximately 10 min walking distance from the Zêzere River (Adewumi, 2020). Anta 1 de Vale da Laje is the last remaining of five monuments: the other four were destroyed by the Vale da Laje megalithic dolmens' complex (Oosterbeek et al., 1992). Several excavation campaigns have been undertaken at the sites (Drewett et al., 1992; Almeida and Oosterbeek 2020), with each campaign season focused on specific research questions within the various aspects of archaeology; e.g., raw materials, pottery, archaeobotanical studies, as well as micromorphological analysis of the sediments of the site.

Micromorphology was used to study sediment from the site following the three steps described above. The samples were taken from the already excavated sections of the archaeological profiles by excavating around the desired/relevant locations and covering them with plaster (Figure 11A). The samples were then processed in the laboratory using the appropriate equipment and following all required procedures; namely, sample drying, sample preparation with epoxy resin and catalyst, cutting of the impregnated samples into blocks shape with a cutting saw, mounting the samples on thin

glass slides and labeling them, marking new glass slides for polishing, gluing the samples to new polished glass slides, subjecting the glued samples to the second and final cutting, and finally cleaning and polishing of the samples to 30-micron thickness for microscope examination (Figures 11B,C).

Micromorphology provides more information about the site evolution and the sedimentary dynamics. It allows the differentiation of natural and anthropic inferences on the site while also assisting in the ordering of the stratigraphic sequence of the site.

This example followed a somewhat user-friendly approach of communicating results to educate in simpler and clearer terms. This avoids losing the content and intended purpose with the application of this methodology to Anta 1 de Vale da Laje. This ensures an easy grasp of the concept of micromorphology as a method not only useful in the academic sector but also as a method for easy communication in a simple and user-friendly manner for educational purposes. It is also important for new producers to consider this method for future work.

## 4 Concluding remarks

Pigment analysis and micromorphology are only two examples of how geosciences may help reconnect teaching processes in both pre-university and higher education through field experiments and participative laboratory work.

The goal of developing an integrated humanities and sciences teaching framework may be reached through the implementation of epistemology/methodology-driven course units. However, the advantage of building from geoarchaeology is that the cognitive process of integration may be structured from concrete objects, within the reach of most children from 7 or 8 years of age.

These methods have been tested for over 20 years and have shown positive results in terms of knowledge building and understanding of complex phenomena and contradictions. These findings converge with the concerns for addressing sustainability as a cluster of challenges requiring inter and transdisciplinary responses.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

## Author contributions

All authors listed have made substantial, direct, and intellectual contributions to the work and have approved its publication.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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