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Cyber-Archaeometry: Novel Research and Learning Subject Overview

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Abstract: The cyber archaeometry concerns a new virtual ontology in the environment of cultural heritage and archaeology. The present study concerns a first pivot endeavor of a virtual polarized light microscopy (VPLM) for archaeometric learning, made from digital tools, tackling the theory of mineral identification in archaeological materials, an important aspect in characterization, provenance, and ancient technology. This endeavor introduces the range of IT computational methods and instrumentation techniques available to the study of cultural heritage and archaeology of apprentices, educators, and specialists. Use is made of virtual and immersive reality, 3D, virtual environment, massively multiplayer online processes, and gamification. The VPLM simulation is made with the use of Avatar in the time-space frame of the laboratory with navigation, exploration, control the learning outcomes in connection to the archaeometric multisystem work. The students evidently learned to operate the VPLM following operations made via visual and home-made scripting, gaining experience in synergy, teamwork, and understanding. The resulting meaningful effects of the cyber-archaeometry with virtual operations and virtual hands, texts, and video equip students especially for e-learning with the required basic knowledge of mineralogical examination, which help to understand and evaluate mineral identification from material culture and provides readiness and capacity, which may be refined in a real polarized light microscopy (PLM) environment.

Keywords: educational; virtual environment; virtual reality; gamification; 3D modeling; cultural heritage; cyber-archaeology; microscope

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1. Introduction

The higher education institutions are progressively looking for new ways to upgrade and update the quality of education, initiate student commitment, and manage knowledge resources. The high-tech development has a major impact on education, and technology-mediated learning is constantly advancing with the introduction of blended learning in educational institutions. Along this rationale, the introduction of novel educational science learning approaches is most welcome. The current state of the art in cultural heritage and new technologies learning in university syllabuses is undermined and new learning management approaches that combine blended programs (in a classroom and from distance) benefits the self-efficacy of students [1]. The various tools used to study material culture and interpret the data and the results derive from the disciplines of information technology, geodesy, GIS, 3D, and virtual reality [2–5].

We are aware that the ability to transmit knowledge and interpretation depends on the complexity of various factors: technology, format, precision, deduction–induction, communication, context, ontology, etc. The archaeological information virtual ontology, or archaeological cybernetics, a further step forward shown here, refers to all the interconnective relationships generated by the datum, the transmission code, and its transmutability. The data are never neutral and, as a result, we must enhance the properties of the affordances [2,6–8].

A brief state of the art of the scientific literature of the novel subject and a comparison with works of a similar nature is unavoidably restricted by the basic foundations laid down by the tools used to record and handle big data taken from archaeological sites and grand excavation and digital imaging and documentation of unearthed finds with ultimate research, education, and pedagogical impact [6,7,9,10]. Earlier work on the present concept is only related to the initial presentation some five years ago [2,8]. Introducing a novel field, it requires an antecedent evolvement of the development of the digital and cyber archaeology task (scientific goal), the formulation, description, and justification of pursuing this new educational tool.

The information technology (IT), artificial intelligence, and high-tech in image processing have developed rapidly in the last decades in many aspects of our life, needs, and pursuits, and the archaeology, cultural heritage, of past cultures and environments have gained a lot. New terminology entered the scientific vocabulary and new disciplines emerged and gradually became establishing assets, such as: virtual environment, VE; virtual reality, VR; massively multiplayer online world, MMOW; virtual worlds; augmented reality, AR; gamification; serious games; and cyber–archaeology [2,11–13]. Thus, from simple digital recordings to multiple storage, interaction, and management of huge data, a cyberspace of the past is emerging.

It is this holistic approach we favor that integrates the insights of traditional archaeology, archaeological science, and digital archaeology, also offering a critical appraisal of the interface between digital methods and archaeological theory. It is the IT revolution that influences archaeological interpretations of techno-social change.

The first and pioneering monograph edited by Forte [14] on virtual archaeology and computer graphic representation of the past introduced and popularized the term virtual archaeology for the first time. The virtual archaeology is mainly visual, static, with graphics and orientated to photorealism [15]. Recently, new approaches have been added using various interactive practices. The 3D modeling is a very useful practice for the identification, monitoring, conservation, restoration, and enhancement of archaeological objects. In this context, the 3D computer graphics can support archaeology and heritage policy, offering scholars a "sixth sense" for the understanding of the past, as it allows them almost to live it [16].

In the late 2000s, cyber-archaeology (CA) transitioned to archaeology as a discipline. In 1997, it was first applied to anthropology and communication studies, where the connection between computer-mediated communications and online behavior as cultural artifacts was explained; see [6,17–20]. Cyber-archaeology was recontextualized when its meaning was expanded to include cybernetics after a workshop at a Theoretical Archaeology Group (TAG) meeting at Stanford University in 2009. CA is the digital management of much partial information in the field [6,7,21]. It is not necessarily visual, but dynamic, interactive, complex, autopoietic (self-organized) [22], and not necessarily oriented to photorealism.

It is Lake's article [18] that epitomized the history of archaeological computer simulation, starting with early 1970s simulation models, and focusing on those developed over the past twenty to twenty-five years, with a prelude to execution of laboratory exercises via browser.

The past cannot be remade but could be simulated, and CA is the process of simulation and reconstruction of archaeological finds or cultural materials. The archeology of the third millennium is able to process, interpret, and transmit much more data and information relative to the last two centuries. Cyber-archaeology provides new energy and excitement into grand narratives of technological revolution and culture change, yet it does further challenge the high-level theoretical explanations. The digital recording methods have the potential to create large, regional-scale databases to ease investigation of high-level theoretical issues. In short, this field, emerging in the 2000s, has shown the potential of the IT revolution, which cuts beyond triteness and instead critically engages both its possibilities and constraints.

Most virtual archaeology research projects were visual-oriented in the 1990s; we now believe they will be cyber-oriented in the third millennium. The discussion of the phenomenology of cyber-archaeologies from virtual archaeology and related applications at epistemological, technological, and methodological levels through some significant theoretical approaches and case studies has been introduced by Forte [14] and later reviewed as cyber-archaeology [6]. Recently, Champion [23] argues that gaming in archaeological excavations are systems, experiences, or arguments.

Though this attempt is incomplete and very preliminary, the defiance is to draw up a cultural proclamation for the foundation of this work from different perspectives and with a variety of multidisciplinary contributions and theoretical discussions.

However, the development and applications to design cyber-archaeology's field of research coupled with archaeometry is being reconfirmed and really is proved valuable (in scholarly resources), and indeed, this post-modern revolution is more cyber than virtual, more sustainable than serving only academic interest [5,7,24,25]. Thus, in the field of archaeology and laboratories, the swiftly and progressive use of 3D digital technologies can design diverse and unexplored workflows in the spawning, portrayal, and communication of data [9,26]. This is making virtual labs practical and convenient and intelligent for e-learning purposes.

In such diverse discipline domains in cultural heritage, this cybernated migration of data and models creates unexpected results and more advanced knowledge, and Bateson thoughtfully (1972) forwards this process as the map-code of the cybernetic cycle. The learning of the code contains big data obtained in the field or processed in the lab, which are mandatory to handle by algorithms, interactors, and large storage machines, which after all generate a triggered feedback in lieu of predetermined inter-connections [6].

The simulation, that is, the enactive-dynamic behavior of the virtual actor and the digital ecosystem, is the focus of the cyber-archaeological process. As a result, different affordances and cybernetic models can be generated by the workflow capable of moving and migrating data from the fieldwork to a simulation environment: each can generate feedback and this is a new map code for the interpretation. The core of the process is not the model, data, or environment, but the interaction, the embodiment and the enacting that is the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses. This is achieved and generated by mutual relations, i.e., it is addressed by cognition [6,22].

Along this amazing new information that offers novel investigatory tools to study the past, we have initiated the cyber-archaeometry project.

The IT and cybernated cultural heritage may be expanded to the archaeometry, also called archaeological science, an interdisciplinary field that emerged at Oxford in the 1960s [27]. Essentially, we make use of the CA methodology to a new concept in teaching higher education apprentices via a virtual environment for the investigation of cultural heritage and archaeological materials with natural sciences [28]. Archaeometry involves applications with the use of available instrumentation and methods to unearthed material culture of archaeological excavations, or basic research implying novel mechanisms for getting, e.g., the age or construction of equipment for solving a particular archaeological question.

It can be divided into seven categories with subdisciplines: (i) dating methods, i.e., physical and chemical dating methods, which provide archaeologists with absolute and relative chronologies, (ii) characterization and provenance methods, i.e., artifact analysis, mathematical methods for data treatment (including computer-based methods), (iii) prospection techniques, i.e., archaeo-geophysical, aerial, and remote sensing methods for the location of buried antiquities, (iv) bio-archaeological techniques for the study of ancient DNA and diet, nutrition, health, and pathology of people, (v) environmental approaches, which provide information on past landscapes, climates, flora, and fauna, (vi) conservation sciences, involving the study of decay processes and the development of new methods of conservation and restoration of ancient remains, and (vii) archaeoastronomy, which is the study of astronomical knowledge of ancient and prehistoric societies from orientated structures, devices, and literature sources [28].

Whichever these thematic divisions are, we stress and promote the concept of a perpetually accredited scientific holistic approach (PASHA), which provides current answers to questions arising from contemporary or future problematic issues and/or reassesses past results in the spirit of updating and reassessment. It is a kind of meta-archaeology, which involves philosophy, archaeology, and natural sciences.

Apart from applications, archaeometry also develops research into new methods and materials to improve errors, increase accuracy, and, thus, reliability. The important contribution of archaeometry to cultural heritage and archaeology remained, for most of the years of its development, known either to a few open-minded archaeologists or to a narrow group of academia [28].

Therefore, a modern approach to cultural education and archaeological sciences is affordable with the use of new technologies: from virtual archaeology in cyber-archaeology and to cyber-archaeometry.

The technological tools derived from the field of natural sciences used to investigate past cultures and archaeometry and the reconstruction of past cultures, achieved from analysis of material culture as well as ideas projected onto material culture, could be approached via theoretical modeling and virtual labs.

The aim of present work concerns a first contact with cyber-archaeometry, which has started with the simulation of a petrographic (optical) microscope with the use of avatar in the time-space frame of the laboratory. The use of virtual reality-gaming software was to enhance the effective education of students in the problem-solving exercises of the archaeometry laboratory, without necessarily their presence in the laboratory. The used digital tools follow the theory of mineral identification in archaeological materials (here granite from Osirion in Egypt). The 3D virtual lab, educational aims, anticipated results, benefits in training on a virtual environment, and learning outcomes will be discussed. The work concept was initiated having in mind the rapid development of e-learning and distance learning processes in higher education establishments, and the need for securing (virtual) hands-on experience of university students to expensive devices for archaeometric work in the field and the laboratory. The benefit of learning is enhanced from prohibited access to student classrooms due to disasters such as the current pandemic and includes accessibility to courses taught from distance [29]. The stakeholders are the apprentices, and the present novelty offers potential to support the managerial and policy decisions. Through properly developed tools to navigation, exploration, and control, one achieves the goal. This goal is made via virtual and immersive reality, 3D, virtual environment, virtual processes, gamification with serious games, and the use of avatars in the time-space frame of the laboratory. The integrated plan triggers show up and develop certain theoretical, cognitive, methodological, empirical, or practical (implemental) goals, which are critically discussed.

2. Overview

A brief review of the scientific literature and a comparison with works of a similar nature, as up to date as possible, is necessary, so that the theoretical new contributions of this research are detailed. However, as can be seen during the development of the present field from the digital and virtual applications, the sources used are pumping ideas from IT, engineering, and mathematics. Reportedly, the novel field of cyber-archaeometry is the simulation design principles that help students' learning and interactions with digital applications in archaeology and cultural heritage, with the experimentation tools in various learning environments. In this aspect, it recalls the integration of science, technology, engineering, mathematics, STEM, with arts and culture (STEMAC); involving computational thinking, engineering education epistemology, computational science education in education, and more generally in learning and teaching approaches and learning objectives [30–34]. The new transdisciplinary and interdisciplinary field that emerges of cultural heritage and archaeology in pedagogics is much valued, in particular in the contemporary emergence from lockdown due to the pandemic, but reappraisal of working conditions too.

The use of the prefix "cyber-" derives from cybernetics, a term that has been given several definitions from the early days of the 20th century [35,36], as a scientific field in retrospect (science of cybernetics and the cybernetics of science) [37] and in other disciplines [38,39]. The word "cybernetics" comes from the Greek word κυβερνητική (kyvernitikí, "government"), i.e., all that is pertinent to κυβερνώ (kyvernó), the latter meaning to "steer," "navigate," or "govern". Cybernetics has evolved in ways that distinguish first-order cybernetics (about observed systems) from second-order cybernetics (about observing systems), such as in the diffusion of water to obsidian hydration dating [40].

The use of cybernetics in the present work:

(1) refers to an interdisciplinary and transdisciplinary field of science and humanities;
(2) incorporates and accommodates every natural or biological dynamical system; and
(3) it develops and interprets phenomena occurring on the space-time 3D set.

Use of cybernetics tools in online learning courses is developing to a sophisticated simulation process [41].

Accepted educational organization models are rapidly challenged by learning technologies. Developments since the 1970s have been reviewed, identifying how the three strands of (a) learning content development, (b) computer-mediated communication, and (c) learning management have been integrated into learning management systems (LMS) made possible by the World Wide Web.

It has been argued that mainstream LMS offer restricted pedagogic opportunities if they are adapted to existing organizational forms, instead of using alternative, easier, and more experienced organizational minimizing constraints. However, prophetically, Beer's work provides us with tools for the redesign of educational systems to make the most benefit from new technologies, guided by Illich's [42] critique of formal education.

Online learning includes offerings that run the gamut from conventional didactic lectures or textbook-like information delivered over the Web to Internet-based collaborative role-playing in social simulations and highly interactive multiplayer strategy games [43].

Furthermore, massive open online courses (MOOCs) provide new opportunities to a massive number of learners to attend free online courses from anywhere all over the world. MOOCs have features that make it an effective technology-enhanced learning model in higher education and beyond [44]. There are a lot of online learning platforms, such us Codecademy, Coursera, Edx, Udemy, etc. E-learning platforms are a fast-growing industry, especially after the advent of Covid-19.

Creating virtual environments offers new ways of educating students. Students could interact extensively with educational and laboratory material, even from their own space. The interaction is very beneficial compared to instructions based on texts or even videos that are not interactive. Virtual environments usually use 3D characters in a game environment, making the training exciting. Moreover, they support multimedia services, hence, students can watch videos, 3D animations, read text instructions, listen to audio instructions, and interact with 3D objects on stage. Those environments can be completely immersive, with 3D interactive functions that simulate, as accurately as possible, a real environment. Metadata is essential for virtual heritage to establish itself as a long-term research area, but metadata has to help the objectives of virtual heritage, which are arguably as much, or more, about education as they are about preservation [16,45].

Virtual training can enable many students to acquire knowledge and skills. On the other hand, virtual labs have been applied mainly in sciences such as physics, biology, chemistry, and in technological sciences.

In an earlier study about the reasons for creating virtual labs, the authors worked on the assumption that a significant portion of students go through labs with little thought about what they need to learn, and just follow closely the written instructions for the experiment to get the expected results. The authors also showed that a primary factor behind this trend is the rigidity imposed by training labs with strict time constraints, large numbers of students, the cost of materials, and security issues. Most of the evidence supporting the value of virtual workshops comes from student feedback. Moreover, the authors of that study found that 75% of students said the software gave them the freedom to explore, focus on the basics of science, repeat procedures, and was easy to use [46].

Several virtual microscope creation efforts have been made but for other purposes.

From a search regarding virtual microscopes, we found several applications and approaches that do not meet the needs of an archaeometry laboratory but mainly applications of biology. Virtual microscopes were introduced into the teaching of histology and pathology at the University of Iowa (USA) in 2000 [47] and at the University of Leeds (UK) in 2005. However, the virtual microscope should not be compared with an electronic simulation of a microscope, which is obviously a complete operating model of a microscope.

At the University of Illinois at Urbana-Champaign in America—this work was funded by NASA in 2003 to provide simulated instrumentation for students and researchers from around the world, as part of a virtual laboratory. The simulation was made for an optical microscope that cost $ 500000, with the aim that every scientist and student can use such a microscope for free. However, NASA has stopped financing it several years later and automatically stopped the development of software [48].

At the University of Delaware, flash technology video and simple operation optical microscope display of the instrument was performed, with no interaction [49].

At South Dakota State University (SDSU) and at New Mexico State University (NMSU), something similar was produced with a little effort to show the use of the microscope as a game [50].

At the Australian Centre for Microscopy and Microanalysis by University of Sydney, a Virtual Transmission Electron Microscopy (TEM) was done. It includes basic imaging with flash technology 2D [51].

The Open University (UK) also developed a virtual microscope (www.virtualmicroscope.org accessed on 3 February 2021). Students are not learning how to use the instrument, but they can enlarge and rotate photos of thin sections from several rocks [52].

Finally, at the Open University of Greece with OnLabs a software application was created, which implements a virtual world simulating the biology lab, not with an avatar; a similar concept to ours, along with the instruments and the rest of objects in it [53].

Regarding the national, regional, inter-regional, and international level, there have been some major efforts that have coined the later evolution of virtual 3D gaming pedagogical dimension. In Europe, the Digital Research Infrastructure for the Arts in Humanities (DARIAH)-funded project is a large-scale, long-term, pan-European endeavor aiming to enhance and support digitally enabled research across the arts and humanities. It does not include cyber-archaeology or cyber-archaeometry works, but remains in our opinion an inadequate level of simply a slow process digitalization of arts and humanities in general, archaeology and cultural heritage being a small part without expected establishment of "digital infrastructures" of the type and level presented in our present work. International appeal for synergy with DARIAH-EU has been endeavored by Schoch et al. [54], based upon work built on earlier interview-based and questionnaire survey research in the "Preparing DARIAH" and EHRI projects, and on synergies with projects such as eCloud, ARIADNE, and NeDiMAH.

In the US, California, San Diego, a web portal is the primary Internet vehicle for communicating with the public and researchers worldwide about At-Risk World Heritage and the Digital Humanities, a cyber-archaeology project awarded a $1.06 million, two-year UC President's Research Catalyst Award from the University of California (UC) Office of the President to a consortium of archaeologists and information technologists on four UC campuses: UC San Diego, UCLA, UC Berkeley, and UC Merced. Cyber-archaeology integrated projects have been made on a regional and local scale [5,55]. The next US mission rests on the Qualcomm Institute (QI) at UC San Diego, which develops technological and institutional innovations including ancient cultures and cyber infrastructure applications from Mayas to Near and Middle East [56].

Visual Studies are established also at Duke University and the DIG@Lab, with the main research topics being digital archaeology, cyber-archaeology, classical archaeology (Etruscan and Roman Archaeology), and neuro-archaeology, and case studies in Europe, Asia, South America, Middle East, and the US [21].

Despite the large number of publications describing projects based on game engines, there are relatively few describing how game engines can be used as interactive frameworks for collaboration, teaching, and videoconferencing. Thus, a cylindrical stereo screen of the HIVE, Curtin University, Perth, Australia, has been developed for such a purpose [57]. It addresses issues that contribute to a serious challenge for virtual heritage: that there are few successful, accessible, and durable examples of computer game technology and genres applied to heritage. Moreover, it argues that the true potential of computers for heritage has not been fully leveraged and they provide a case study of a game engine technology not used explicitly as a game but as a serious pedagogical tool for 3D digital heritage environments. They combine immersive 3D models and video conferencing, particularly for large scaled cylindrical displays, such as the curved stereo display (e.g., the avatar mirrors that track gestures of the speaker and triggers slides by pointing at the relevant objects; another option is to simply have a hand that points to objects in the scene—the virtual hand moves and points according to the tracked hand of the speaker).

All these major enterprises provide an accurate, precise, workable, simulated, and learning environment of ancient sites, archaeological environments, and 3D artifacts, which contribute decisively to the integrated and holistic study of past cultures, making the field work and museum objects accessible to society and hitherto offer a superior pedagogical potential.

3. Instrumentation

Figure 1 shows the simulation of a petrographic (optical) microscope with the use of an avatar in the time-space frame of the laboratory, that navigates, explores, and controls the learning outcomes in connection to the archaeometric multisystem work.

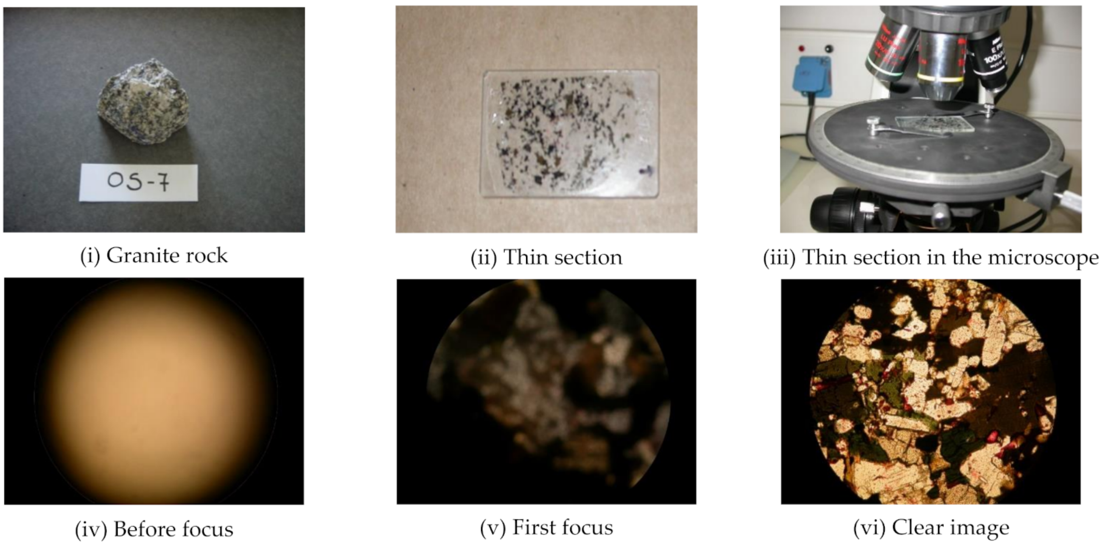
Figure 1. Polarized light microscopy (PLM) with various components (© lab of archaeometry, University of the Aegean, Rhodes).

Use is made of virtual and immersive reality, 3D avatar, virtual environment, massively multiplayer online processes (MMOP) (virtual processes), and gamification with serious games. A demo is presented online [58]. The benefits include advantages concerning repeats as trial and error at any time, overcoming costly demands of purchasing electronic equipment.

Virtual Development and Materials

Here, we create a different software, which is based on 3D serious games, using immersive technology with a high degree of presence for the students. The use of avatars, 3D graphics, and gamification aims to ensure success not only in learning the microscope but also in detecting the minerals through information, images, and short videos including evaluation exercises for both knowledge and skills.

This virtual microscope has been designed to train students in learning and using the polarizing microscope. They use virtual hands to operate the instrument guided by speech and texts by human avatars, a laboratory assistant, and a geoarchaeologist (Figure 2A) and snap shots of the material culture from the Osirion Temple at Abydos, Egypt, along with the preparation of the thin section on a glass, the setting of the thin section onto a physical PLM table and images before focus, adjustment, and the clear image with the minerals (Figure 2B).



(**B**)

Figure 2. (**A**) Virtual microscope laboratory; the instructor, the apprentice, the VPLA and the operating hands. (© Authors 2021); (**B**) (i) A piece of granite from the Osirion Temple at Abydos, Egypt, (ii) the derived thin section on a glass, (iii) the setting of the thin section onto a PLM table, (iv) before focus, (v) adjusting the blurriness with rotating lenses, and (vi) the clear image with the ingredient minerals (© Lab of Archaeometry, Rhodes, Sample No OS-7/RHO-139).

It is very useful for students to learn the material culture composition and technology of stone implements from the archaeological excavations. It is imperative for the knowledge of knowing the recipes for making ceramics, the composition of rocks, and using databases to identify the types of manufactured artifacts and quarries used to produce implements or monuments. They become also acquainted with the ingredients of ceramics, become familiar with the minerals (main component of rocks), and acquire information on archaeo-materials.

The use of a polarizing microscope in the archaeometry laboratory concerns the enlargement and analysis of small samples, showing the structure of small fossils and the texture of rocks. The observation and analysis of the samples is done by examining a thin section, a few micrometers thick. Initially, a piece of material of about 1 mm and an area of 2 square centimeters is detached. This slice is then smoothed to the point where a flat surface is created like a mirror. The sanded surface is pasted on a glass surface and the sanding continues until a thickness of about 30 micrometers. A light beam of polarized light passes through the petrographic microscope to this thin section.

An example of analysis comes from the Abydos, the greatest of all cemeteries and the home of god Osiris. The adjoining building is the Osirion, which features a central "Island of Osiris" made of granitic stone and surrounded by an artificial canal and sandstone wall, all of which were deep underground in Pharaonic antiquity, invisible to the eye and unknown to all but the priests. A sample of the granitic assembly pillar was examined and was dated by Optical Stimulated luminescence (OSL) to 1980 $\pm$ 160 [59] in accord with the archaeological age Middle Kingdom, 11th to 14th dynasties, 2134–1690 BC. Mineralogical qualitative examination revealed: Quartz: moderate, Albite: moderate, Orthoclase/Microcline: low, Biotite: low, and Actinolite: sparse quantities [60].

Figure 3 shows the thin section microphotograph of the studied granite, and Figure 4 is the place of origin, the Osirion Island in Egypt, surrounded by sandstone walls and the granitic pillars.

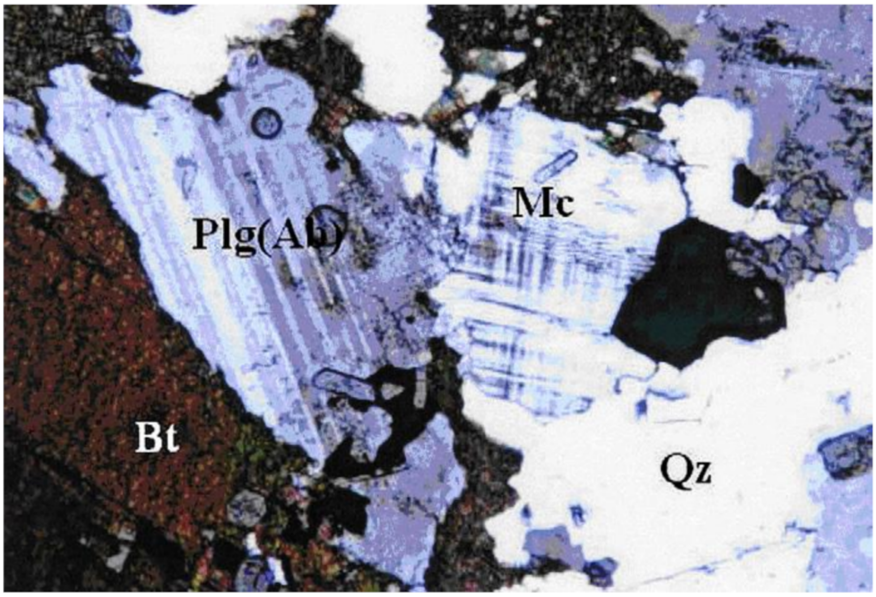


Figure 3. Thin section microphotograph of granite OS7 (crossed polars, magnification x60). Qz, quartz, Plg (Ab), plagioclase feldspars (Albite); Mc, microcline; Bt, biotite.(© I. Liritzis).

Figure 4. (**Left**) Top view of Osirion at Abydos with the granitic pillars and the inner part flooded with water. (**Right**) I. Liritzis (left) and Prof. El Gohary (right). Sampling comes from the pillars (© I. Liritzis).

For the creation of the virtual class, the priority was the 3D model of the microscope (Figure 5a), which was given for free by the creator Olek Pieta. Two movements were added to the model of the microscope with the 3D Unity game machine (raising and lowering the bank for focusing and rotating the objective lenses for magnification). From the free libraries of 3D models on the Internet, furniture, and objects (Figure 5b) as well as 3D humans (Figure 5c) were added to the space of the laboratory. Basic 3D movements (walking, sitting, hand movements, speech movements) were added to the 3D humans to make their presence in the laboratory as real as possible. A 3D hand model (Figure 5d) was also placed so that the student could operate the microscope.

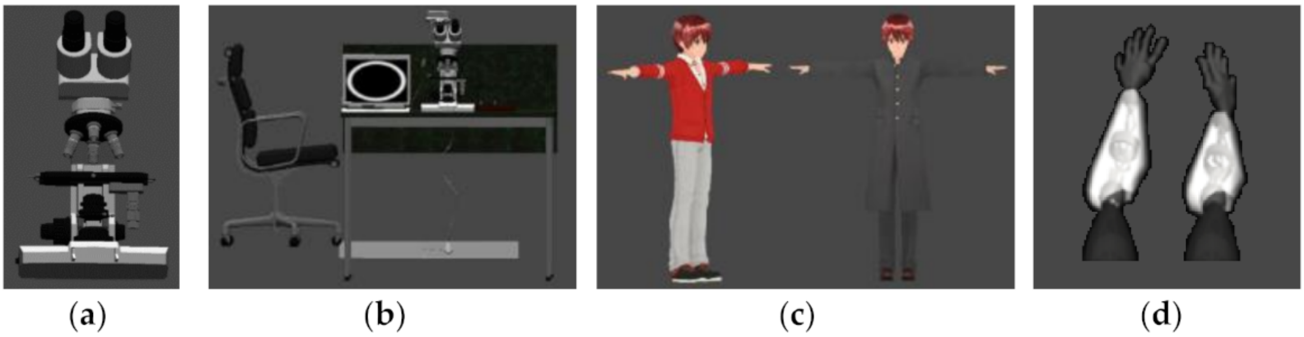


Figure 5. 3D models of microscope (**a**), furniture (**b**), humans (**c**), and hands (**d**) (© Authors).

The development of the application made by the 3D Models and Game Engine Unity3D. Visual scripting PlayMaker was used for most of the triggering scenarios between user and visual microscope. PlayMaker is a plugin for 3D Unity offering an intuitive structure with States, Actions, and Events to quickly build behaviors (Figure 6).

The students learn to operate the VPLM following the next operations, which have been made via visual scripting and other home-made scripts: (1) turn on the instrument by pressing the ON switch, (2) place the thin section of the sample they want to observe, on the microscope bank, (3) the thin section is placed on the bank, they must rotate the focus screws, (4) cautious rotation of the macro screw until they see the sample clearly and then they focus with the micrometer screw to see it as clearly as possible.

Texts and recorded texts from digital speakers were used to communicate with the students. For the educational material of mineral identification, a same virtual class was used with two boards in which the necessary texts, photos, and videos were presented. The navigation in the educational material can be done with the 3D hands of the virtual microscope but also with keyboard keys.

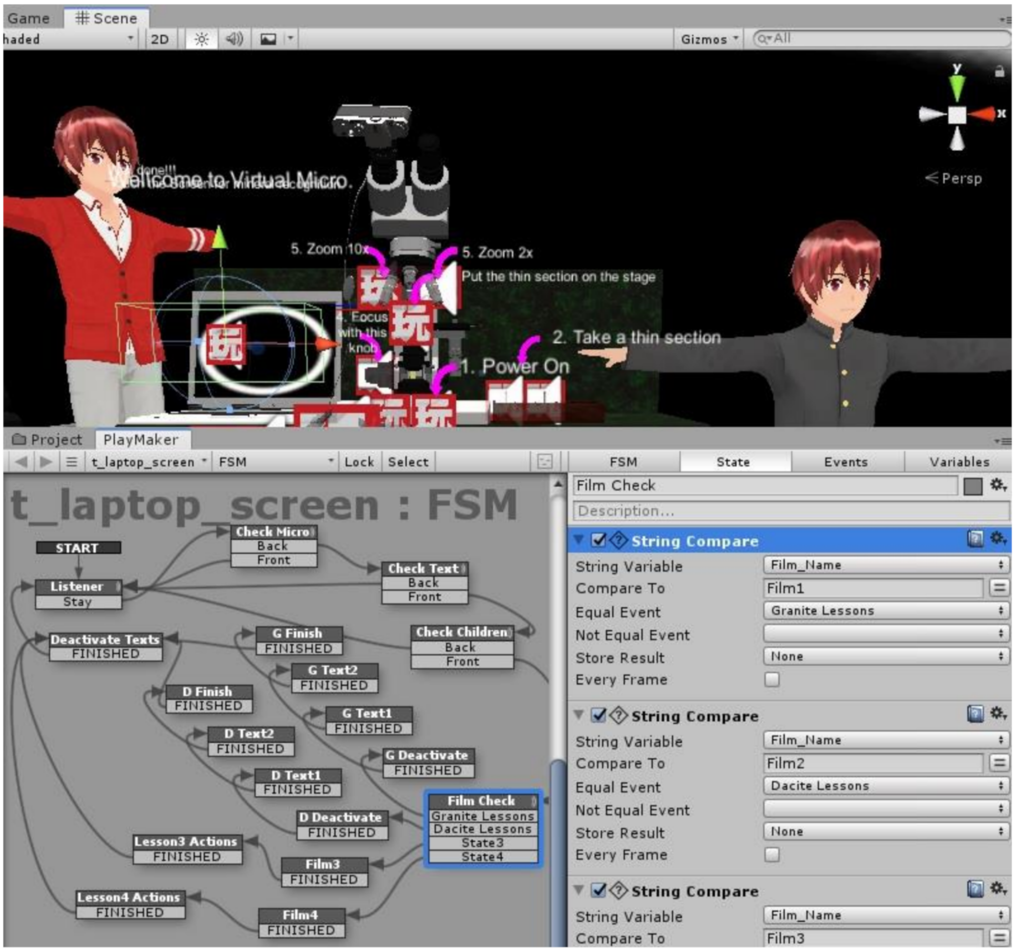


Figure 6. An example of programming inside 3D Unity with PlayMaker, which for every step the student controls his hands in space (passing through invisible trigger points) and activates respective algorithm and directs the apprentice to get the right answer (© Authors).

A logic diagram used to identify the minerals contained in granite rock (Figure 7). Students observing the properties of minerals through photos and video clips and by following the logical diagram are trained to recognize granite minerals.

The identification of minerals follows a gradual process and is examined visually by distinguishing the minerals according to properties that can be distinguished from the passage of polarized light such as color, relief, cleavage, and pleochroism by rotating the microscope bank.

The logic diagram for the identification of minerals in a granite thin section was coded with Playmaker and integrated into the software using the necessary images, adding text with explanations, and allowing the student to explore the next characteristic of the diagram with the (left) or (right) selection button of the teaching material board, pressing with keyboard keys or student 3D hands.

The first characteristic that is observed is the *color*. The colorless minerals (left) are usually quartz and feldspar and the colored minerals (right) biotite or hornblende.

The second characteristic that is observed is the *relief*. The relief of a mineral is how it appears to stand out in relation to the medium that surrounds it. The difference in refractive index between tangential crystals gives the impression that some of them are elevated relative to others. This also makes the boundaries of some minerals appear sharper.

For the colored minerals on the thin section of granite rock, the ones that have a low relief are usually biotite, chlorite (left) and those with moderate relief hornblende (right) (Figure 8).

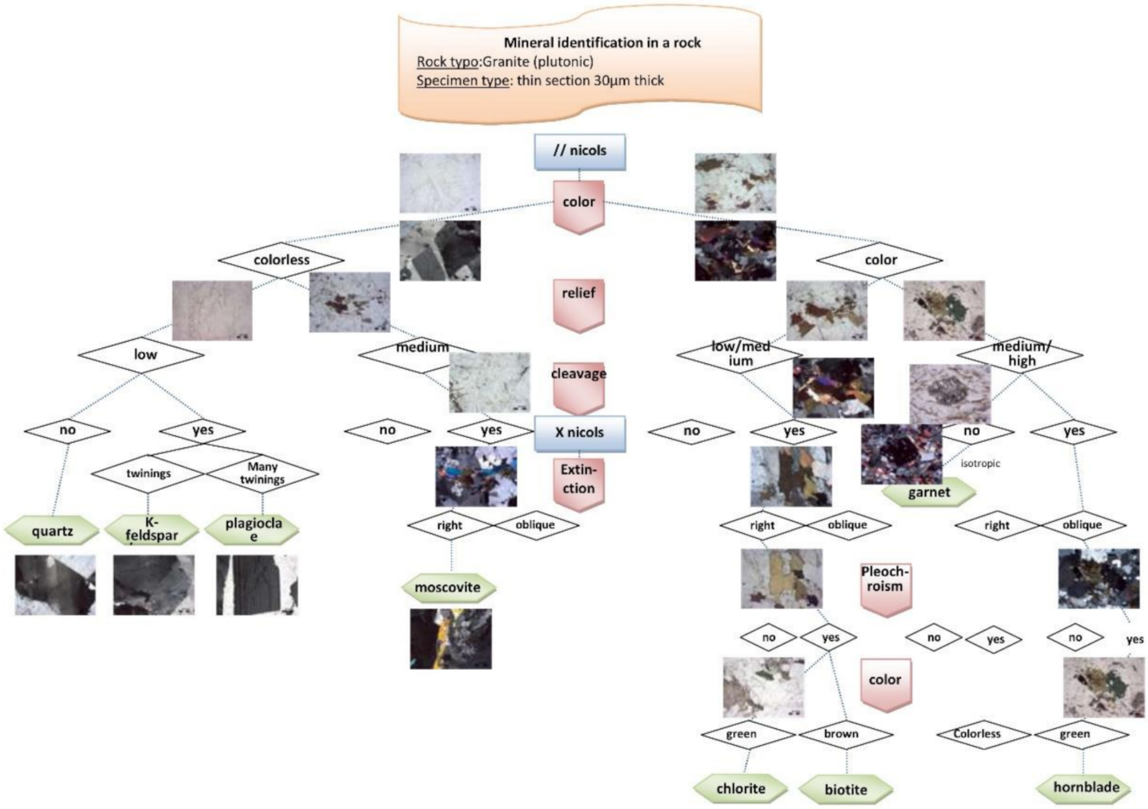


Figure 7. Steps to identify minerals in thin sections of rocks (pers. Comm. Prof. I. Iliopoulos, University of Patras).

Figure 8. A photo capture of the virtual class (© Authors).

The third feature is *cleavage*. It is the property of a mineral to break or tear at certain levels, at which the atomic structure of the mineral is weak. For the thin section of granite in colorless minerals, if cleavage is not observed, no mineral is recognized. If cleavage is noted, then it is probably muscovite. No presence of cleavage also means no identification for the colored granite minerals. With cleavage we can identify biotite and chlorite (left) and hornblende (right) in conjunction with the next observation feature, pleochroism.

The colored minerals change the intensity of their color by rotating the bank of the microscope. This property (*pleochroism*) is important as it can be used to distinguish between minerals, which are difficult to distinguish macroscopically. Pleochroism occurs only in colored minerals and is observed only with a polarizer. For chlorite and biotite, it is observed that they change color from light brown to dark brown. To make this change visible, two video clips are included in the virtual microscope. Two video clips also presenting the color changing of the hornblende, where color ranges from yellow-green to brown-green.

During the mineralogical examination, the main diagnostic features for the identification of minerals are the crystalline form (color and relief), cleavage, and other optical properties as the polarized light pass through them [47].

These virtual operations with the virtual hands, texts, and video equip students with the required basic knowledge of mineralogical examination, which has a twofold value: (a) to understand and evaluate mineral identification from material culture, and (b) readiness and capacity that may be refined in a real PLM environment. Moreover, apprentices acquire a large experience on the content of archaeo-materials, learn to function the device and associated physical-chemical mechanism, become familiar and gain experience in an abundance of free chosen time.

4. Discussion

The construction of the virtual PLM (VPLM) forms the foundation for further development of virtual archaeometric equipment for learning the methods and extract the relevant information. It establishes a new convenient and low-cost application bound to make future archaeological analysis faster and more precise. Moreover, through remote connection, scholars from all over the world can participate in the identification and identification of antiquities. Because the operation can be repeated, this application gives all students the opportunity to operate. Analyzing various results from different angles and viewpoints is no longer just a standardized operation and answer. The physical device cannot return to the previous action for observation at any time during operation. This application can repeat steps so that students can analyze the results in more detail in their studies. Last, if the physical device is used for a long time, there will be problems with inaccurate identification. This application can indeed reduce the cost of equipment replacement and measurement errors.

With this rationale, the cyber-archaeometry (CAm) is the digital IT process of simulation, restructuring, and management of archaeometric processes from the field of natural sciences in relation to material culture, investigated variously (dating, prospection, analysis, technology, provenance, archaeoastronomy, etc.), either as optimum recruited image or as targeted research quest [2]. If this cyber era is seen as a retrospective concept, one has to compare the two approaches in the development of digital archaeometry from archaeological procedural (processualism) in post-procedural thinking, in order to achieve the analysis of hybrid forms of both approaches, achieved by procedural tools (statistical analysis and quantitative methods in different fields, mathematics, geography, archaeometry, anthropology, archeology, and related disciplines). The above is an example of the emergence of cyber-archaeometry.

It is most needed in the present era with the pandemic where online lectures and especially learning involve (virtual) hands-on instrumentation for measuring material culture.

One of the first findings (of archaeological processualism) from the digital point of view was the use of statistical processing and quantitative methods in various fields, including mathematics, geography, archaeometry, anthropology, archaeology, and related disciplines. The critique of subjective methodologies illustrated the need for hyper-taxonomies to understand the past, and this archaeology of computing seemed a tangible and sustainable way for the dream of the process: an objective "scientific" expounding.

In the field of data interpretation, processing, and exchange the digital representations provide new perspectives and a modern approach to training and education, but also to science. It is important to those who understand virtual cultural dynamics through virtual labs [2,6,8]. The motto, "The past cannot be remade but could be simulated" may now be rephrased to "The archaeometric instrumentation and methodologies cannot be available but could be simulated".

There is no doubt that the novel e-learning technologies for cyber-archaeometry have great potential for learning and the organization of education. However, from our project and student interactive process, it is concluded that it is the design and application conceptualization that determines the impact of the present and more archaeometric methodologies, and it is evident that people have widely differing views about their proper use. To understand these, it is prudent to recall and reflect on an earlier investigation about the short history of learning technologies [41]. The introduction of the Internet, and the World Wide Web, appears to have made possible holistic learning for all three of these aspects—content delivery, communications, and learner management—to be integrated into a single system. Hence, the learning management systems (LMS) or the virtual learning environments (VLEs) began to emerge, contributing to online access to computer-based materials culture, providing communication tools, and allowing teachers to provide assessments, track students, build course materials, and manage the whole process.

Cyber-archaeometry started with the VPLM but will have a rapid development, in the near future, for other techniques and methods of the archaeological sciences enriching the curricula with similar virtual environments. Such a case is the obsidian hydration dating, which is one of the dating methods to determine the age of an obsidian (natural volcanic glass), which was a sharp blade for prehistoric people's daily needs. A hydration layer is formed inside the rock, with a width that varies depending on the time of water penetration, the temperature and humidity of the environment, and its special physicochemical structure. The longer the diffusion lasts, the older the obsidian object. The 3D representation of the process of hydration of obsidian is primarily educational, so that students understand the mechanism of hydration in different sources of obsidian and from different environments through a visual language. At the same time, however, the 3D presentation of dating with obsidian hydration will prove the network of codes of interpretation (mathematical algorithms, equations) and diffusion time. Through the simulation, the disordered but with predominant orientation of moving water molecules into the obsidian tool surface, the apprentice gets a sense of the diffused water rim, which is a function of the age of the tool since its last use [40] (Figure 9).

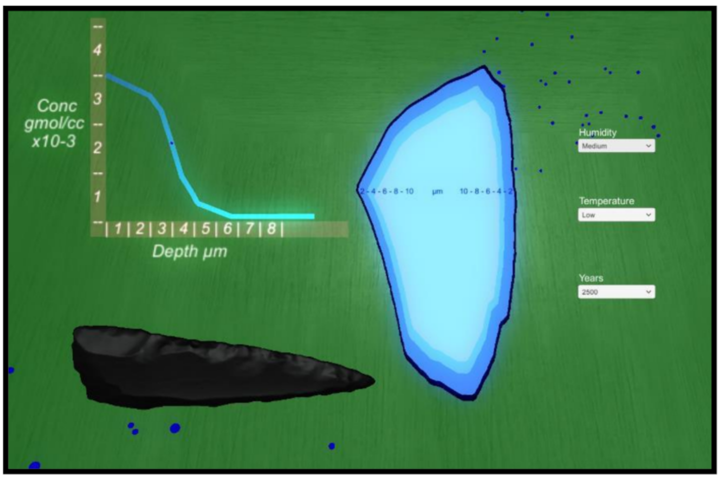


Figure 9. Screenshot from the obsidian diffusion software; the obsidian blade, the simulated diffusion rim in dark blue, and the X-Y plot of concentration of water molecules as a function of depth (work in progress, see our video simulation in [58]).

Undoubtedly, technology is providing tools that provide radical new opportunities for education, but simply adding technology to the existing mix is not enough. We need to use technology to develop better pedagogies, and most importantly, to redesign educational organization at all levels, from the course to the national system, to allow potential benefits to be realized [61,62]. The rapid changes in technology affects educational roles and learning outcomes, and cyber-archaeometry falls within this new era. Surely the completion of a reasonable spectrum of available archaeometric methods to a virtual merging environment needs the financial support of the Institution, but from a complexity management perspective, it is important to note that new education subjects, such as the cyber-archaeometry, require a new role in educational policy. Our thesis towards the importance of the individual, along with the pre-existing and continuously evolved theoretical frameworks, concerns the general (world, language group, etc.) and local policy and organization, without discrimination. At any rate, it is not necessary for the board to know or understand all issues, but to ensure that intelligence and operation function well and are a properly balanced [63] viable system model restated by Liber [41].

The latter is reinforced by the results that showed that students as adult learners should be involved in the design and improvement of software. This is in line with the theory of Mindtools, according to which educational software should function as a tool in the service of students, to develop critical thinking and to acquire a high level of knowledge and skills [64].

5. Pedagogical Assessment

The experiencing in the acquisition of knowledge is efficient with an enactive cognitivism, taking cognition as an action of inculcation in the teaching. In terms of the novelty of the virtual lab in the cyber-archaeometry discipline, the cognition is enhanced by the comprehensive triggering experience and these capacities belong and refer to cultural contexts.

Hence, the attainment of data from material culture concerning constituents, physical-chemical mechanisms for dating, characterization, provenance, locating buried antiquities, and more, could be identified in the mutual interaction between virtual action and experience and consequently between action and knowledge.

The present project searched the ability of a virtual archaeometry lab with digital characters and gameplay elements, to increase student participation and to see how the learning performance was affected using virtual lab exercises. Equally important were the research questions posed as part of our goal: Could students express their educational needs? Could they be involved in the design of educational applications? What are the students' opinions about the effectivity of such educational software in archeology?

The construction of the VPLM, the students' reactions during the working, and the interactive process and operational tasks have produced interesting results.

Briefly, the meaningful effects of the cyber-archaeometry with a 3D VPLM (in a similar manner for other methods and electronic devices from archaeometry) are summarized as follows:

The educational aims and anticipated results that were satisfied:

- Execution of laboratory exercises from internet via browser.
- Making a virtual lab for education of university students (e-learning or from distance) without physical presence.
- Learning the functioning of lab instruments for archaeometric work.
- Enable students to discover knowledge through these processes, but also to interpret in their own way the laboratory results.

The benefits in training and advantages of learning from the VPLM included:

- To perform at any time without help from assistants of the lab.
- Cost saving
- Avoiding disasters and loss of material.
- Repeat of an experimental exercise.

- Partial steps can be repeated, giving students the opportunity to analyze the process from different perspectives and opinions.

Concerning the learning outcomes, students:

- recognized content of thin sections (minerals, organic matter, fossils, scrap fragments, mineralogical structures etc);
- acquired a wide spectrum of the content of archaeo-materials;
- accepted trial and error;
- understood the functioning of equipment;
- were familiarized, and;
- gained experience in synergy, teamwork, and understanding.

The results have shown that the 3D laboratory space, the game elements, and the automated exercises, excited the students and increased their desire to participate in the educational activities. A positive result was the satisfactory acquisition of knowledge based on their evaluation results, in relation to the level of information they met. The level of difficulty is a matter for further research, as it can also be a deterrent to using the software.

The existing learning processes in classrooms and laboratories (where available, literally in exceptionally few cases) follow the traditional PowerPoint or oral teaching followed (in some cases) by homework and essays. However, in the archaeology and cultural heritage investigation one needs measuring equipment, basics in natural sciences. In the development of cybernated methodologies, the analysis results are a message for the higher education service policy and practitioners in the institutions of different types and levels, which along with potential users' characterization open a new era in educational sciences.

With these results, the research problem and research goals and pedagogical aims are fully identified and satisfied in this work [57]. The scientific level of the present pedagogical concept has certainly the potential for generalization in any geographical, cultural, and organizational area.

Overall, handling scientific instruments, data collection, data processing and analysis, observation of results, interpretation-explanation of observations, and presentation of results are skills that are very important for students to acquire during their laboratory practice [65].

However, the instruments used in the archaeometry laboratory have a high cost of purchase and maintenance when used by students in the context of laboratory exercises. In addition, the time that students can use the instruments is determined by the opening hours of the laboratory and is relatively limited, while the number of students who practice on the same instrument makes it difficult to use.

Lack of resources in universities is a constant problem that in many countries creates an inability to perform many experiments in archaeometry laboratories. With the use of virtual labs—as, here, the cyber-archaeometry project—the above restrictions may no longer prevent students and researchers from enhancing their skills and knowledge in the most effective learning outcome, the experiential participation.

6. Conclusions

The VPLM for cultural heritage in the digital era is made via virtual tools and the development of the application is made with 3D modeling and the Game Engine Unity3D as well as for the purpose designed algorithms. The 3D virtual polarized light microscope has been constructed in a virtual laboratory environment and enables the student to comprehend complex physical/archaeometrical terminology and instrumentation. Making use of free codes and written scripts, apprentices followed a methodological way to identify minerals in archaeological materials, learning their characteristic properties in relation to operational modes of the PLM. Apprentices are becoming familiar and tuned with the modern trend of learning (distant learning), and institutions and tutors complement costly equipment for archaeometric results with a built-up cyber-archaeometry project. Here, we initiated a first step for the cyber-archaeometry, while next constructions could include spectroscopic and dating methods, etc. The benefits emerging from the concept of developing virtual archaeometric environments include recording and managing many diversified big data, applicable to a wide spectrum of archaeometric devices and methods, and provide strength, modernization, and alternative experiences in education making use of the high-tech and IT tools.

Amongst the meaningful effects and merits of the cyber-archaeometry with a 3D VPLM are: execution of laboratory work from the Internet via a browser, making a virtual archaeometric lab for education of university students (e-learning or distance), and learning the operation and methodology of archaeometric devices for measurement processes related to chronology, provenance, and technology strengthen effectively students' knowledge and triggers interest and curiosity for interpretation of laboratory results. We have documented the benefits in training and advantages of learning from the VPLM and satisfactory learning outcomes, with major issues being the gaining of experience through synergy, teamwork, and understanding.

The research implies a new educational tool, which can be expanded to other devices and methods without limitations in the way of acquisition of knowledge in the particular course of archaeological sciences. It provides clues for an integrated policy to the current and future learning processes taken by higher education institutions and policy makers.

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