Special Issue

Susana França de Sá* and Márcia Vilarigues

Integrating expertise for teaching conservation science to cultural heritage conservation students – A closer look at radiation, colour and museum lighting topics

https://doi.org/10.1515/cti-2023-0001
Received January 5, 2023; accepted March 14, 2023; published online April 18, 2023

Abstract: Introduction to Conservation Science (ICS) is a curricular unit (CU) from the bachelor's degree in Conservation-Restoration at NOVA School of Science and Technology. This CU was created in 2017 to fill a gap in the academic degree – the need for a bridge between fundamental sciences (1st year) and conservation-restoration diagnosis (3rd year). For this reason, ICS was designed with the main goal of teaching 2nd year students how to look at, approach and solve problems of Cultural Heritage, through the combination of reflexive thinking and object-led analysis. ICS was first designed by an expert in Conservation Science with academic background in physics. However, from the perception of the students' struggle to understand the purpose of ICS subjects to their future professional activity, a professor with expertise in Conservation and Restoration was invited in 2019 to work together in the re-design of the CU, through an integrated approach between the two experts. ICS was then revised with the introduction of new perspectives and topics, as well as new communication routes to students. This work highlights this partnership as a good practice methodology to involve conservation-restoration students into science, focusing on the ICS classes specifically dedicated to radiation, colour, and museum lighting.

Keywords: academic training; collaborative teaching; conservation science; cultural heritage; fundamental sciences.

1 Introduction

Over the past century, we have witnessed the progressive merging of conservation and restoration with science and technology. Conservation Science has arisen as a discipline that develops new research technologies and methodologies for the study of materials and collections of our cultural heritage (Golfomitsou, 2015; Heritage & Golfomitsou, 2015; Heritage et al., 2014).

The areas of research in Conservation Science include material degradation studies; *in-situ* and ex-situ analysis and characterisation; technical art history; portable instrumentation; sensors and dosimeters; scientific methods for dating, provenance, and authentication; and statistics, modelling and chemometrics for cultural heritage. By studying heritage materials, their production and construction, as well as their mechanisms of decay, the aim of Conservation Science is to improve the conservation of both tangible and intangible qualities of Cultural Heritage.

In this context, the curricular unit (CU) 'Introduction to Conservation Science' (ICS) was created in 2017 as part of the 2nd year of the bachelor's degree (B.S.) in Conservation-Restoration at NOVA School of Science and

***Corresponding author: Susana França de Sá**, LAQV-REQUIMTE, Department of Conservation and Restoration, NOVA School of Science and Technology, Campus da Caparica, 2829-516 Caparica, Portugal, E-mail: susana.sa@fct.unl.pt. https://orcid.org/0000-0003-2445-9361
Márcia Vilarigues, VICARTE, Department of Conservation and Restoration, NOVA School of Science and Technology, Campus da Caparica, 2829-516 Caparica, Portugal

Technology (FCT NOVA), in Portugal. ICS aims at developing reflexive thinking in the decision-making processes involved in the safeguard of Cultural Heritage. This curricular unit was created to provide the concepts serving as the basis for the professional training of students as conservators, while seeking to make them aware of current research and new methodologies at the forefront of studies of Cultural Heritage materials and praxis.

In the beginning, ICS was conceived and taught by one person, an expert in Conservation Science (CSE) with education in physics, which defined the most relevant subjects to be included in ICS syllabus: the principles of the scientific method and the experimental design; the mechanical, physical, and chemical magnitudes of the materials; the electromagnetic radiation in cultural heritage study, deterioration, and museum lighting; and science communication. These topics were selected based on her awareness of the need to develop solid science foundations in students, making them able to search and understand scientific bibliography, and to identify knowledge gaps and advance in research, but especially, to develop communication skills in students, making them capable of sharing ideas with different agents of Cultural Heritage, in particular chemists and physicists.

Although the importance of Conservation Science to the profession of Conservation and Restoration is already recognized nationally and internationally, normally it is not presented in a single course; instead, it is often spread over different CU such as Physics and Analytical Methods applied to the study of cultural heritage. Also, these CU are mostly found only at the Master level and commonly taught by a singular lecturer, without academic training or practical experience in conservation and restoration, which constitutes one of the novelties of ICS teaching methodology, presented in this paper.

A large percentage of students coming to the bachelor's degree in Conservation-Restoration at FCT NOVA do not have a strong background in exact and natural sciences, as most students come from art training programmes in the secondary school (a percentage of circa 80%). This influences their receptiveness to chemistry, physics, and mathematics, especially due to the distinctive languages and communication routes of subjects between professors and students, but also due to the lack of immediate bridges between theory and application in conservation and restoration.

From this observation, the CSE decided to invite a professor with expertise in Conservation and Restoration (CRE) to enroll in the re-design of ICS, with the goal of creating a clear bridge between exact and natural sciences and cultural heritage conservation praxis already in ICS classes. Even though the authors recognise that most conservation science lecturers will make the effort to put science into context for conservation practice, our experience led us to curiously observe that students relate more to science when those lessons are taught by a joint-team of scientists and conservator-restorers. This partnership brought a straightforward perspective and conceptualization to students, as it was especially relevant in highlighting the applicability of ICS subjects in their future professional conservator activity.

The integrated teaching methodology was crucial to strengthen the students' awareness on the relevance of this CU and on the use of exact and natural science knowledge in the planning of experimental designs to solve problems of the Cultural Heritage.

To stress this partnership as a good practice in conservation education, this research presents two examples of ICS classes, dedicated to radiation, colour, and museum lighting.

2 Methods

ICS is taught at the 2nd year students through 4 h of theoretical-practical (TP) classes per week, in a total of 56 h of contact with students (6 ECTS), 14 weeks. To provide a strong basis for future professionals of Conservation of Cultural Heritage, ICS syllabus is divided into four main topics:

(1) The Fundamentals (12 h, 4 weeks)
   a. What is Conservation Science?
   b. The principles of the scientific method.
   c. Data acquisition, treatment, and statistical validity.
   d. The principles of experimental design.

(2) Materials Properties and Deterioration (12 h, 3 weeks)
   a. The mechanical, physical, and chemical magnitudes of materials: deformation, elasticity and tensile strength, thermal properties.

b. Superficial and bulk deterioration.
c. Deterioration agents in Cultural Heritage.

(3) Radiation in Cultural Heritage (16 h, 4 weeks)
a. Interaction of radiation with matter.
b. Colour perception and measurement.
c. The various ranges of electromagnetic radiation in cultural heritage characterization – imaging, elemental and molecular examination techniques.
d. Radiation as source of deterioration.
e. Radiation in museum lighting sources – criteria of selection.

(4) Conservation Science into Practice (12 h, 3 weeks)
a. Building an experimental design to solve problems of the Cultural Heritage.
b. Science communication work focused on subjects/case studies selected by the students.

By providing a thorough grounding in decision-making for the practice of conservation and restoration, ICS syllabus intends to transmit to students the role and importance of Conservation Science in tackling problems that affect cultural heritage. For instance, this enables students to better decide about lighting sources for storage, museum exhibition rooms and photographic studios, how to better hang artworks by eliminating incorrect tensions, how different analytical techniques are complementary in information about a cultural heritage object, how to assess and select preventive strategies for a collection and how to decide on a conservation treatment by planning a good experimental design, among other subjects, with a strong support in science.

At the end of ICS, students will be able to:

- Read and undertake bibliographic research;
- Apply the principles of the scientific method in their research plan;
- Understand and use scientific concepts related to physical, mechanical and physical–chemical properties of materials;
- Understand the methodologies to study the materials of works of art and of conservation and restoration, as well as ageing phenomena with the use of photo documentation and analytical instrumentation;
- Define the best methodology (experimental design) to answer questions of the cultural heritage such as lighting, hanging artworks (tensions), detection of colour change, and identification of materials (elemental and molecular) and causes of deterioration;
- Assess and present data, based on the critical assessment of advantages and limitations of several imaging and analytical instrumentation;
- Understand the rational of analytical protocols for the assessment of conservation treatments;
- Communicate science to the public.

Classes normally consist of alternating theoretical and practical periods: a maximum of 1-h for presenting theory and selected case studies based on peer-reviewed articles, followed by 2 to 3 hours of practical exercises in the classroom or object-led analysis in the lab. Through guided readings of articles and problems resolution, students are exposed to the concepts of the CU's theoretical programme within the context of practical application.

Both ICS lecturers (CSE and CRE) hold a PhD in Conservation of Cultural Heritage, although focused on different fields, and followed by different career pathways. The CSE has a solid background in Cultural Heritage made of glass and ceramics, especially on materials characterisation, technical art history, and in-depth research on archaeometry and provenance studies, whereas the CRE is specialised in modern materials and contemporary art conservation, with relevant work in the development of preventive and active conservation strategies. From the conjugation of these two lecturers, it was possible to re-design ICS with the broadening of ICS subjects to more materials and problematics and to introduce new exercises and more effective communication routes to students, strongly relying on known scenarios and contexts by the students to drive their oral participation.

ICS classes were planned to follow four main sections – (i) introduction and theory, (ii) case studies presentation, (iii) bibliographic references with extra reading material for students; and (iv) practical work which can involve group work (exercises or discussions), lab demonstrations and/or lab work conducted by the students. These different teaching methodologies enabled the transmission of science subjects to students crossing three keyways of training, namely 'Knowledge', 'Knowing how to do' and 'Soft skills'.

One of the first changes resulting from this partnership was the start of all ICS classes with a question/problem coming from the Cultural Heritage, almost simulating a future situation in their professional activity. The question/problem that is exposed to the students in the first PowerPoint slides should then be answered throughout the class based on the knowledge selected for that day. This question was though to trigger their attention and to develop observation and reflexive thinking skills in students. The question must be presented with an image illustrating an artwork or a cultural object with a problem/observation that is deepened or even solved with the use of physics and chemistry knowledge.

In the practical period, the resolution of academic exercises and engagement with case studies by the students is crucial for their learning process. The direct application of science concepts in this section enables students to develop skills of conceptualization. Several group discussions and problem-solving oriented activities are proposed to prepare them to plan experimental designs and to find solutions for problems commonly found in their future professional activity. This also enables students to develop teamwork skills,

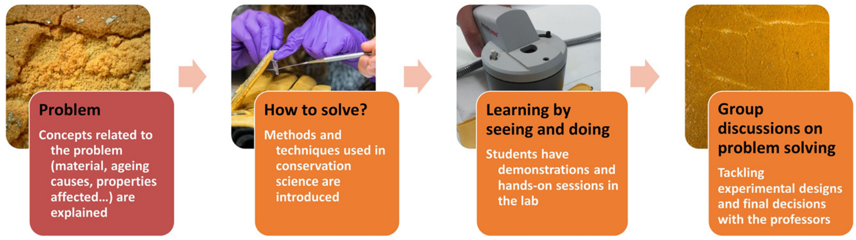

Figure 1: Basic structure of an ICS theoretical–practical class.

so valuable in this profession. Training students questioning skills is also one of the main goals of ICS and a highly valuable competence in Cultural Heritage professionals.

Demonstration of analytical procedures in the laboratory is also a useful tool to transit students from conceptualization to the application of concepts; helping them to master the subjects learned in class. Figure 1 summarizes the basic structure of an ICS class. In the first and second parts ('Problem' and 'How to solve?'), the introduction to a science subject is made, and all concepts and theory are explained, ending with the presentation of case studies that are collected from research papers and projects, when possible, carried out at the Department (i and ii). At the end of this part, extra bibliography can be shared with students to better explained the usefulness of the lesson, and when possible, with the attempt to include references relating to materials or conservation subjects that students showed interest during the class but were not covered (iii). In the following parts ('Learning by seeing and doing' and 'Group discussions on problem solving'), the class finishes with theoretical knowledge into practice through exercises, lab demonstrations, lab work, or discussions on conservation decisions supported by scientific research (iv).

3 Discussion and results

To better illustrate the teaching methodology and scores achieved by the ICS partnership between the two experts (CRE and CSE), this section discusses two classes, dedicated to 'Light and Colour' and 'Museum Lighting'. Table 1 summarises the main concepts and learning outcomes defined for each class.

For the 'Light and Colour' class, right after entering the classroom, students are engaged with a painting by William Turner, *Light and Colour (Goethe's Theory) – the Morning after the Deluge Moses Writing the Book of Genesis* from 1843. Side by side with the painting, students see the question "Is colour an intrinsic property of objects?". After students' first reaction to the painting aesthetic and question, some words mentioned by them are selected by the professor to be written in the board. Then, another image is shown composed of an object repeated

Table 1: Main concepts and learning outcomes of 'Light and Colour' and 'Museum Lighting' ICS classes.

Class	Light and colour	Museum lighting
Concepts	Nature of light; Electromagnetic spectrum; Absorption and reflection; Colour and colour perception; Additive and subtractive colour mixing; Colour systems.	Light and radiation; Light intensity (lux); UV radiation (μW/Lúmen); IV radiation; Photolysis and rate of decay; Spectroscopies and spectra; Correlated colour temperature (CCT); Colour rendering index (CRI).
Learning outcomes	To know the electromagnetic spectrum, especially the visible region; To understand colour in objects as a result of three main factors (incident radiation, object interaction to radiation, and detector); To use colorimetry as a tool for analysis and study of colour and colour change in conservation.	Being able to distinguish between different sources of lighting – incandescent, fluorescent and LED; Being able to read absorption and emission spectra; Being able to select lighting sources according to advantages, limitations and lighting purpose (short and long-term display, photodocumentation, storage, lab work).

3 times, each time illuminated by different lighting sources. Again, the same question is posed to students, “Is colour an intrinsic property of objects?”. From this question, light is always a concept expressed by the students as a possible factor influencing colour perception – which becomes the trigger concept to start the theoretical explanation on the subject, ‘Light and Colour’. Questioning students about “What is Light?” enables the introduction of concepts related to the nature of light as a wave and a particle, and its interaction with matter through reflection, absorption, refraction, and dispersion, with the establishment of correlations to the object physical and chemical nature (Williamson & Cummins, 1983). This first part also ends with the introduction of the electromagnetic spectrum and the different sources of radiation (Williamson & Cummins, 1983). In this class, the focus is the visible region and the phenomena of colour perception, tackling mostly light absorption and reflection by the materials of works of art. The role of the detector in colour perception is also explained to students as an important factor influencing this perception, which has been especially taken into consideration when presenting artworks in a gallery to the public and planning museum lighting. The colour perception is explained in more detail, introducing to students the human eye features and the theory of the three stimuli, always making a correlation between how these tree factors (source, object, detector) influence colour perception, pretty much as an analytical equipment commonly used in the lab in terms of its source of radiation, sample/object characteristics and detector with certain sensitivity, resolution, precision, and associated error. After students learn these factors, another painting is shown, the *Sunflowers* by Vincent van Gogh from 1888, and students are asked to describe the colours they see in a brief way. Then, the same painting with drastic colour changes (due to ageing) is shown, and students are asked again to describe the colour change they see and to share it in class. From this share among students, it is easily perceptible that different students have different opinions in terms of colour change description, with distinctive terms being launched such as “darkening”, “became greenish”, “yellowed”, etc. This debate makes the perfect opportunity to introduce how colour can be scientifically qualified and quantified with the use of colour parameters (hue, saturation, and brightness), coordinates, and colour spaces (Oleari, 2016), as well as the extensive use of colourimetry in conservation research (Plutino & Simone, 2021). The previous painting by William Turner is revisited to explain Goethe’s theory on colour in the XIX century, and its evolution up to the CIELab colour system in the XX century and the so important total colour variation formulations, widely used in conservation research. Students are then challenged to make their own colour measurements in an object (commonly a painting or a document) by using a handheld colourimeter and filling in an exercise sheet with the calculation of L^*, a^*, b^* coordinates average, standard deviation and variation, and total colour variation (ΔE^*). Students then must discuss if the calculated coordinate colour variation (ΔL^*, Δa^*, Δb^*) is significant by carrying out a statistical assessment of the data and conclude if the total colour change (ΔE^*) is perceptible to the human eye (Mahy, Van Eycken & Oosterlinck, 1994). This exercise is crucial for students to consolidate the given concepts and to learn how to present data correctly. The peer-reviewed articles selected to be discussed in the class can be two from (Berns et al., 2005; Fonseca et al., 2010; França de Sá Ferreira et al., 2016; Montagner et al., 2017, 2018; Muñoz-García et al., 2016), which also includes research conducted at the department. The inclusion of research papers carried out by former students or more senior researchers from DCR FCT NOVA revealed to be especially important for students to help them place themselves in the future of their academic and professional activity. From these articles, students clearly learn on how colourimetry can be used to better assess deterioration but also to decide on conservation treatments or preventive strategies.

For the class, ‘Museum Lighting’, students are firstly asked about “What is the mission of a museum?”. Again, keywords mentioned by them are selected by the professor according to their relevance for the subject and written on the board. Very often, students name “exhibition”, “conservation”, “display”, and “inventory”. Then, a part of the Portuguese law governing museums (Lei Quadro dos Museus Portugueses, No. 47/2004 of 19 August) is shown, from which the Article No. 3, Alinea a) is highlighted, stating that museums should have a structure allowing them to:

> Guarantee a unitary destination to a set of cultural assets and enhance them through research, incorporation, inventory, documentation, conservation, interpretation, exhibition, and dissemination, with scientific, educational and recreational purposes (Portuguese Law No. 47/2004, of 19 August).

From this first discussion, students become completely aware on the role of a museum and their obligations as future professionals in the field. Then, if museums must preserve but also exhibit their collections to the public, another question is posed to students, “How to select proper museum lighting that would not promote deterioration?”, with a debate between preservation, presentation and photodocumentation requirements being launched. For this debate, their experience in the curricular unit ‘Photodocumentation for Cultural Heritage’ (taught at the same semester) is highly important. Students become aware they have been using UV emission lamps and halogen lamps emitting IR radiation without really asking themselves about possible alternatives or the reasons behind having such lighting in the studio.

By raising their curiosity in this subject, the electromagnetic spectrum is revisited, now not only focused on the visible region but mostly on UV and IR, and their impact in materials decay, such as molecule dissociation and molecule vibration (Michalski, 2018), possibly leading to fading, yellowing, cracking, and brittleness, among other damages. The concept of absorption is recalled, focusing on it as a phenomenon resulting from the absorption of radiation with a wavelength corresponding to the energy gap between energy states. It is also explained to students that not every material absorbs UV frequencies, so not all would suffer deterioration from an UV exposure, which for some it is strange. Transitions to the excited state are revisited, as well as the concept of photolysis. The use of glass picture frames containing UV filters for protecting an artwork are described as an example to prevent artworks from UV deterioration, as they contain molecules capable of absorbing that energy, releasing it in the form of heat. In contrast, some molecules commonly found in cultural heritage materials do suffer chain scission when exposed to UV energies.

Accordingly, it is also explained that only molecules absorbing IR radiation undergo vibration when exposed to that source and consequently, their kinetic energy increases, possibly leading to an increase in the deterioration rate. IR radiation can be used to characterise artwork materials by carrying out infrared spectroscopy in samples or *in situ* but can also lead to deterioration by exposing artworks to incorrect temperature if used for longer times. By establishing these associations between absorption but also decay consequences, students often ask “How can we know if a material absorbs UV or IV energies?”, which makes the perfect opportunity to introduce UV–Vis–IR spectroscopy as a tool to characterise the chemical composition of artworks (rightfully understood by them) but also as a powerful tool to identify which wavelengths can negatively affect a certain object (Picollo et al., 2018). Understanding the concept of the spectrum, how it is created and how to interpret it is highly helpful for students to establish correlations. The usefulness of the technique in the acquisition of lamps emission spectra is also taught, by teaching them how to read the spectrum and use that information to better select museum lighting. The pros and cons of daylight and lamps emission are addressed to students and how each lamp bulb functions are explained in detail, focusing mostly on four types: traditional and halogen incandescent bulbs, fluorescent bulbs, and light-emitting-diode (LED) bulbs (Druzik & Michalski, 2012). Then, science concepts and units related to measuring light (illuminance, lux), relative UV radiation (μW/lm) and IR radiation (for instance, through T increase) are discussed, as well as the important light quality parameters such as colour rendering index (CRI) and correlated colour temperature (CCT) (Michalski, 2018), which are key parameters in the selection of lighting bulbs for photo-documentation. An important subject transmitted to students is that it does not matter to strictly focus our attention on the selection of a bulb with low amount of lux without knowing its emission spectrum because lux only gives information on the intensity of light, i.e., the intensity of the visible radiation, leaving aside other important regions of radiation such as UV and IV, due to their damaging factors. This is particularly stressed to students and then tested on several hands-on exercises carried out by them in the photographic studio with the use of light and UV portable meters, as well as by the acquisition of spectra with a UV–Vis spectrophotometer on different materials. These exercises illustrate very well the different levels of information that can be obtained by each equipment (light and UV meters) or more advanced techniques (UV–Vis–IR spectrophotometer), but most importantly, the richness of the association of different levels of knowledge in the selection of proper lighting for museums according to the required needs – photodocumentation, storage or display (permanent or temporary).

The peer-reviewed article to be discussed in the class is (Lunz et al., 2017), as it discusses the ability of LED light sources to be tailor-made and adjusted to create lighting solutions for artifacts more sensitive to specific regions of light or radiation, while maintaining acceptable lighting quality. By showing the UV–Vis absorption spectra of an artwork pigment with and without the binder, as well as the UV–Vis–IR emission spectra of several light bulbs with different CCT, makes a perfect case study to summarise the important science concepts related to this subject. Moreover, peer-reviewed articles focusing on the use of light and UV radiation to reproduce and accelerate ageing are also discussed.

Does this approach to teaching works? There are multiple ways to determine this. First, students' numerical ratings of ICS classes have been very positive since 2019. These ratings have often been accompanied by comments from the students that expressed how the lecturers' enthusiasm for the materials and subjects increased their interest in the course.

The average grade of ICS students in 2017 was 13 out of 20 (13/20), and four of 26 students dropped out the CU; in 2018, the average grade was 14/20, but 3 students dropped out and 1 failed. It is important to mention that in this year, the CRE was already participating but just in few lessons and ICS was still functioning according to the first model. In 2019, following an in-depth change of the CU, the average grade increased to 15 out of 20, no one dropped out, and no one failed. This success (zero fails) has been registered since that year and in 2022, the average grades was almost 16/20. Further, and in the authors view, more importantly, many students believed that their increased interest in the subject resulted in improved performance and learning in the following courses.

4 Conclusions

ICS main goal is to teach students in Conservation and Restoration how to look at, approach and solve problems of Cultural Heritage, leading them to combine the principles of the scientific method, reflexive thinking, and object-led analysis with more straightforward or advanced analytical instrumentation. Through the presentation of science subjects particularly relevant in the conservation of Cultural Heritage, discussion of case studies and peer-reviewed research papers, along with demonstrations at the lab and hands-on exercises, ICS seeks to develop a strong critical thinking in students, allowing them to make better decisions in the preservation of cultural heritage. Physics and chemistry are taught from the perspective of Cultural Heritage, and through the perspective of two experts working in this field in two different fronts: a Conservation Scientist and a Conservator-Restorer. This partnership was fundamental to increase students' awareness on the relevance of science and on the use of scientific language and approaches in their decision-making.

Our main goals are to create the necessary conditions for students to acquire valuable knowledge from the foundational standpoint and to learn, by practice, how to apply those concepts. We believe that an effective learning environment will expose students to fundamental concepts and techniques of conservation science while maintaining a clear connection with practical aspects of conservation practice. This is pivotal to keeping students' interest and for them to feel that their studies are providing them with useful knowledge, keeping them engaged in their learning experience.

It is extremely relevant to a conservation-restoration student to also acquire competencies in the domain of *how to do*. Students at this level must be exposed to a high amount of foundational knowledge. They should, however, clearly understand the role and impact of such knowledge in the heritage preservation. Topics to be taught should focus on tasks that require applying fundamental knowledge in the design of problem-solving tools, framed in the context of historical objects and institutions responsible for preserving and caring for cultural heritage.

One of the strongest aspects of ICS teaching methodology is the constant search for the active participation of students in the exposure and teaching of science subjects, giving them a greater sense of agency and engagement with the lessons, and helping them to make strong relationships between ICS contents and contents from previous and further CUs.

Acknowledgments: The authors are thankful to all ICS students for their precious input on the curricular unit teaching methodologies.

Author contributions: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.
Research funding: This work was supported by National Funds through FCT-Portuguese Foundation for Science and Technology under the Projects (UIDB/50006/2020 and UIDP/50006/2020 – LAQV; and UIDB/00729/2020 and UIDP/00729/2020 – VICARTE).
Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

References

Berns, R. S., Byrns, S., Casadio, F., Fiedler, I., Gallagher, C., Imai, F. H., … Taplin, L. A. (2005). Rejuvenating the appearance of Seurat's A Sunday on La Grande Jatte – 1884 using color and imaging science techniques–a simulation. In *ICOM committee for conservation preprints: 14th triennial meeting The Hague* (Vol. 2004).

Druzik, J. R., & Michalski, S. (2012). *Guidelines for selecting solid-state lighting for museums*. Los Angeles: Getty Conservation Institute.

Fonseca, A. J., Pina, F., Macedo, M. F., Leal, N., Romanowska-Deskins, A., Laiz, L., …Saiz-Jimenez, C. (2010). Anatase as an alternative application for preventing biodeterioration of mortars: Evaluation and comparison with other biocides. *International Biodeterioration & Biodegradation*, *64*(5), 388–396.

França de Sá, S., Ferreira, J. L., Matos, A. S., Macedo, R., & Ramos, A. M. (2016). A new insight into polyurethane foam deterioration–the use of Raman microscopy for the evaluation of long-term storage conditions. *Journal of Raman Spectroscopy*, *47*(12), 1494–1504.

Golfomitsou, S. (2015). Educating future professionals in conservation science: The challenges of an interdisciplinary field. *Studies in Conservation*, *60*(Suppl. 2), 39–47.

Heritage, A., Anuzet, C., Andersson, E., & Antomarchi, C. (2014). The ICCROM Forum on Conservation Science 2013: A collaborative partnership for strategic thinking. In *ICOM-CC 17th triennial meeting Melbourne* (pp. 15–19).

Heritage, A., & Golfomitsou, S. (2015). Conservation science: Reflections and future perspectives. *Studies in Conservation*, *60*(Suppl. 2), 2–6.

Law No. 47/2004, of 19 August (2004). Diário da República. 1.a série-A, n.º 195 (pp. 5379–5394). On Lei-Quadro dos Museus Portugueses.

Lunz, M., Talgorn, E., Baken, J., Wagemans, W., & Veldman, D. (2017). Can LEDs help with art conservation? – Impact of different light spectra on paint pigment degradation. *Studies in Conservation*, *62*(5), 294–303.

Mahy, M., Van Eycken, L., & Oosterlinck, A. (1994). Evaluation of uniform color spaces developed after the adoption of cielab and cieluv. *Color Research and Application*, *19*(2), 105–21.

Michalski, S. (2018). *Agent of deterioration: Light, ultraviolet and infrared* (Vol. 17). Canadian Conservation Institute.

Montagner, C., Linhares, J. M., Vilarigues, M., Melo, M. J., & Nascimento, S. M. (2018). Supporting history of art with colorimetry: The paintings of Amadeo de Souza-Cardoso. *Color Research & Application*, *43*(3), 304–310.

Montagner, C., Linhares, J. M., Vilarigues, M., & Nascimento, S. M. (2017). Statistics of colors in paintings and natural scenes. *JOSA A*, *33*(3), A170–A177.

Muñoz-García, A. B., Massaro, A., & Pavone, M. (2016). Ab initio study of $PbCr(1-x)S_xO_4$ solid solution: An inside look at Van Gogh Yellow degradation. *Chemical Science*, *7*(7), 4197–4203.

Oleari, C. (2016). *Standard colorimetry: Definitions, algorithms and software*. John Wiley & Sons.

Picollo, M., Aceto, M., & Vitorino, T. (2018). UV–Vis spectroscopy. *Physical Sciences Reviews*, *4*(4), 1–14.

Plutino, A., & Simone, G. (2021). The limits of colorimetry in cultural heritage applications. *Coloration Technology*, *137*(1), 56–63.

Williamson, S. J., & Cummins, H. Z. (1983). *Light and color in nature and art* (p. 512). New York: Wiley.