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Teaching Paleoradiography Theory Using E-learning – A Participatory Action Research Study with Undergraduate Archaeology Students

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Abstract

This article presents the development of an e-learning paleoradiography short course for undergraduate archaeology students using participatory action research. The use of x-rays in archaeology is well known and yet studies exploring the pedagogic preferences of students are lacking, particularly for online learning. To address this shortfall 100 students were invited in two equal groups to participate and provide feedback for an e-learning course which ran in April-May and July-August 2021. Participants required internet access, a university email address and four hours to complete the course. Initial feedback was used to improve the course for a second iteration. The course attracted international interest with students from 22 unique universities in nine countries. The majority were females in their mid-twenties with a slight dominance of second year students.

A total of 52 participants (52%) completed the course to receive a certificate. Free-text responses provided rich and valuable feedback for course improvement far superior to blunt Likert scales of evaluation. Results highlighted critical issues including webpage navigation, device compatibility and alternative formats for learning content. Whilst the integration of a discussion forum failed to encourage inter-participant engagement, universal requests for the judicious use of images and videos were apparent for online learning.

Introduction

Paleoradiography is the application of radiography upon archaeological specimens, with the prefix “paleo” denoting ancient. Archaeological investigations use paleoradiography on a wide range of excavated or preserved objects: human and animal bones, metalwork, ceramics, and textiles (Beckett and Conlogue 2020; Chhem and Brothwell 2008; O’Connor and Brooks 2007). Radiographs aid in the assessment of preservation state and construction methods; assist the diagnosis of pathology or trauma; or act purely as educational tools (Caple and Garlick 2018; Licata et al. 2018). Despite its value and importance within archaeological practice, there is a lack of dedicated instructional material concerning paleoradiography for undergraduate archaeology students. This study concerns the development of an online, asynchronous, short course (e-learning) delivered in April–May and again July–August in 2021 which addressed threshold concepts in paleoradiographic theory. Threshold concepts have been described as conceptual gateways where the learner achieves a transformed way of understanding without which they cannot progress within a topic (Meyer and Land 2003). A participatory action research approach has been adopted for this research, where learners (participants) are actively engaged in course improvement. As extolled by Kemmis, McTaggart, and Nixon (2014), participatory action research enables an understanding of how practices are conducted from within; facilitates a shared dialogue between investigator (teacher) and participants; allows equal participation by both parties; and fosters the understanding of practice from an individual and community level.

The value and limitations of e-learning within archaeology education have recently been explored by Peuramaki-Brown and colleagues (2020), with useful insights for appropriate design and delivery of learning materials. Unsurprisingly, online courses within archaeology are common, with examples ranging from Massive Open Online Courses (MOOC) (Alcock, Dufton, and Durusu-Tanrıöver 2016), Small Private Online Courses (SPOC) (Scherjon, Romanowska, and Lambers 2019), and full undergraduate or postgraduate degrees. The topic of paleoradiography is well represented within academic literature, with a variety of textbooks addressing issues such as the production, application, and interpretation of radiographs in archaeology (Beckett and Conlogue 2020, 2020; Chhem and Brothwell 2008; Creagh and Bradley 2000; Lang and Middleton 2005; O'Connor and Brooks 2007). However, thus far no attempts have been made to investigate the teaching of paleoradiography at an undergraduate level using e-learning. This research not only aims to promote the teaching of a previously underrepresented area of archaeological education, but also hopes to foster a collaborative approach tailored for undergraduate archaeology students.

Methodology

This study used a participatory action research design due to the involvement of students in the evaluation of the course design and learning content. The course was led by a subject expert (the author), with stakeholders being self-identified through voluntary participation and feedback. Action research is based upon four phases of development often repeated in cycles, as recommended by Riding, Fowell, and Levy (1995) (Figure 1). Each cycle is itself based upon the Plan-Act-Observe-Reflect phases of Kemmis and McTaggart (1981). Within this research the *Plan* phase involved creating the course using best available guidance, *Act* enabled participant access to the learning content, *Observe* collected participant feedback, and *Reflect* allowed the investigator to identity themes and actions to be taken for positive change. Upon completion of Cycle 1 a revised plan was made, amendments completed, and then it was rereleased to new participants for further evaluation. Consequently, by Cycle 3 the course had undergone two iterations. Participants were made aware that the study contributed towards the author's teaching qualification in higher education and was granted ethical approval by Canterbury Christ Church University (reference ETH2021-0073).

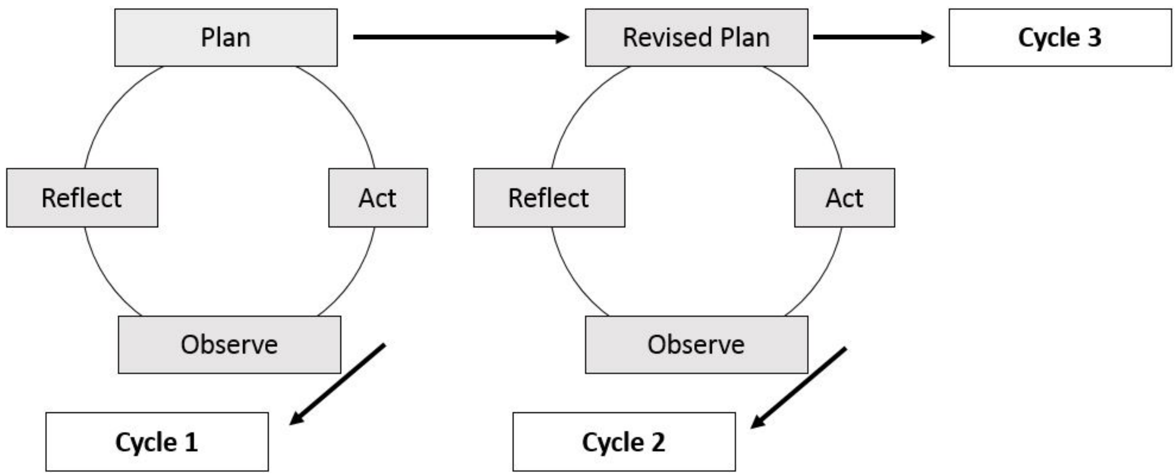


Figure 1. The process of action research based on cycles (Riding, Fowell, and Levy 1995).

Sample Size and Selection

The course was open to undergraduate archaeology students of any year of study from any university, worldwide. A sample size of 50 participants per cycle was chosen to provide sufficient feedback for data saturation and counteract potential participant attrition frequently associated with online courses (Shaw, Burrus, and Ferguson 2016). Specific requirements included access to the internet, a university email address, and sufficient time to complete the learning content and evaluation (four hours in total). The requirement of a university email address allowed confirmation of association with a higher education institution, although not the program of study. The course was intended for those who understood the English language to an academic level, however this was not assessed at enrollment.

An email campaign was conducted to advertise the free online course using institutional email addresses freely available online (n=92). In addition, the author made use of the British Association for Biological Anthropology and Osteoarchaeology email list commonly populated by both academic staff and students. Recipients were furnished with a cover letter explaining the course (and the author's academic assessment) along with a participant information sheet and an advertisement flyer. A request was made to share these documents with undergraduate students, with no financial reward for doing so. A certificate of completion, sent out by email, was offered to participants as a means of incentive.

Course Design and Delivery

Design and layout of the course was based upon the principles of clarity, logical progression, and use of multimedia as recommended by Vai and Sosulski (2016) and, likewise, held in common with virtual learning environments found in higher education. A simple black, gray, and white palette was initially adopted in Cycle 1 (Figure 2) with diagrams offering occasional color (Figure 3). The first version of the course provided navigation buttons on the left and right of each webpage. Each section adopted a *one-page* scrolling approach to content instead of segmented webpages, beginning with an introductory video (~1:40 minutes) and learning objectives, finishing with a summary and self-test quiz. The author created videos using *point of view* narration (similar to GoPro) of x-ray equipment at Canterbury Christ Church University to explain key points with demonstrations. Video montages were collated and exported as single files using PowerPointTM, and ranging from 3:21–8:25 minutes. Throughout the course a personal approach was used to convey information, relying upon experience and opinion in speech bubbles (Figure 4).

An asynchronous design was chosen to allow for the greatest involvement by participants. True to most distance-learning formats, the participants could access the course at any time, pause, and return as they chose (Marmon, Vanscoder, and Gordesky 2014). The course was delivered on paleoimaging.com, a non-monetized research website that is owned, designed, and operated by the author to explore the use of imaging in archaeology. Wix.com was selected for the creation of the webpages due to its versatility, adaptability, and integration of multiple media platforms. The course was noncredit, nonaccredited (by related professional bodies), and not affiliated with Canterbury Christ Church University in an official capacity other than the aforementioned granting of ethical approval.

Figure 2. Typical layout of course page during Cycle 1 of the course.

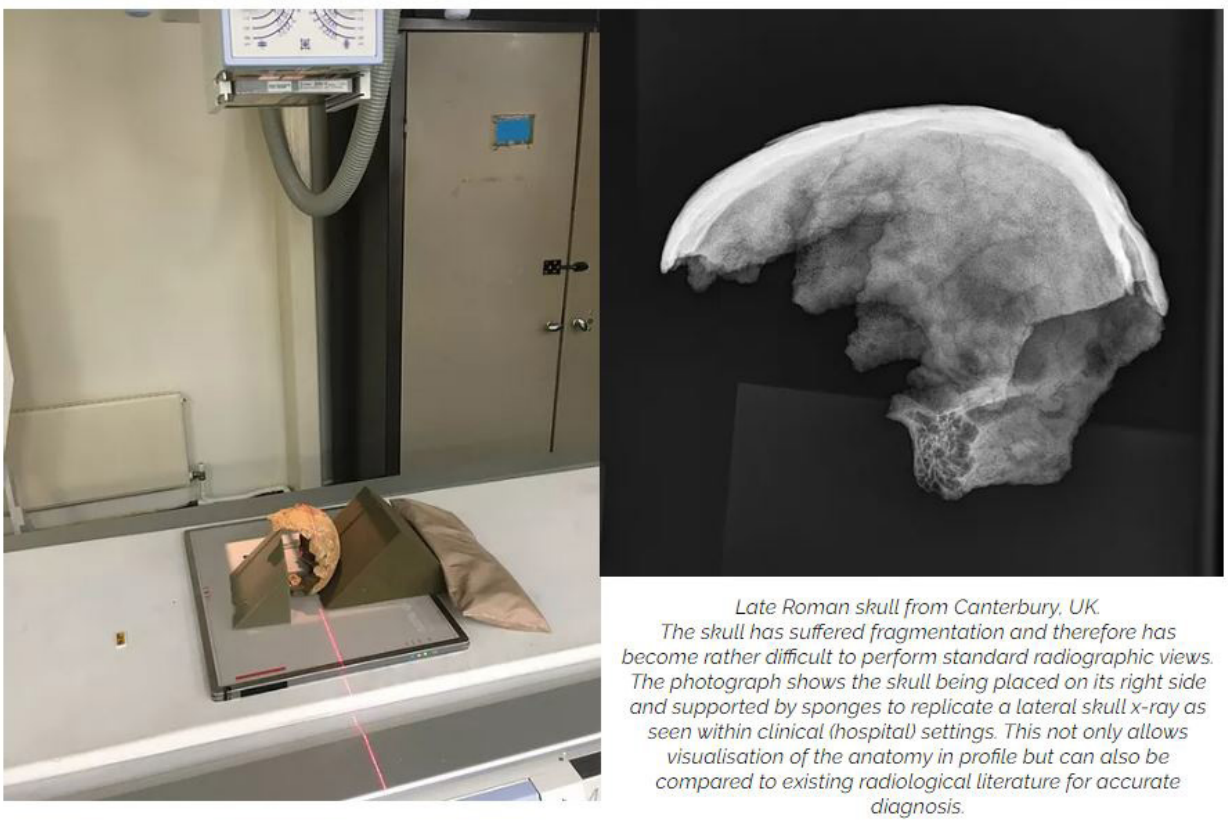


Figure 3. Typical images with photography and radiography alongside descriptive text.

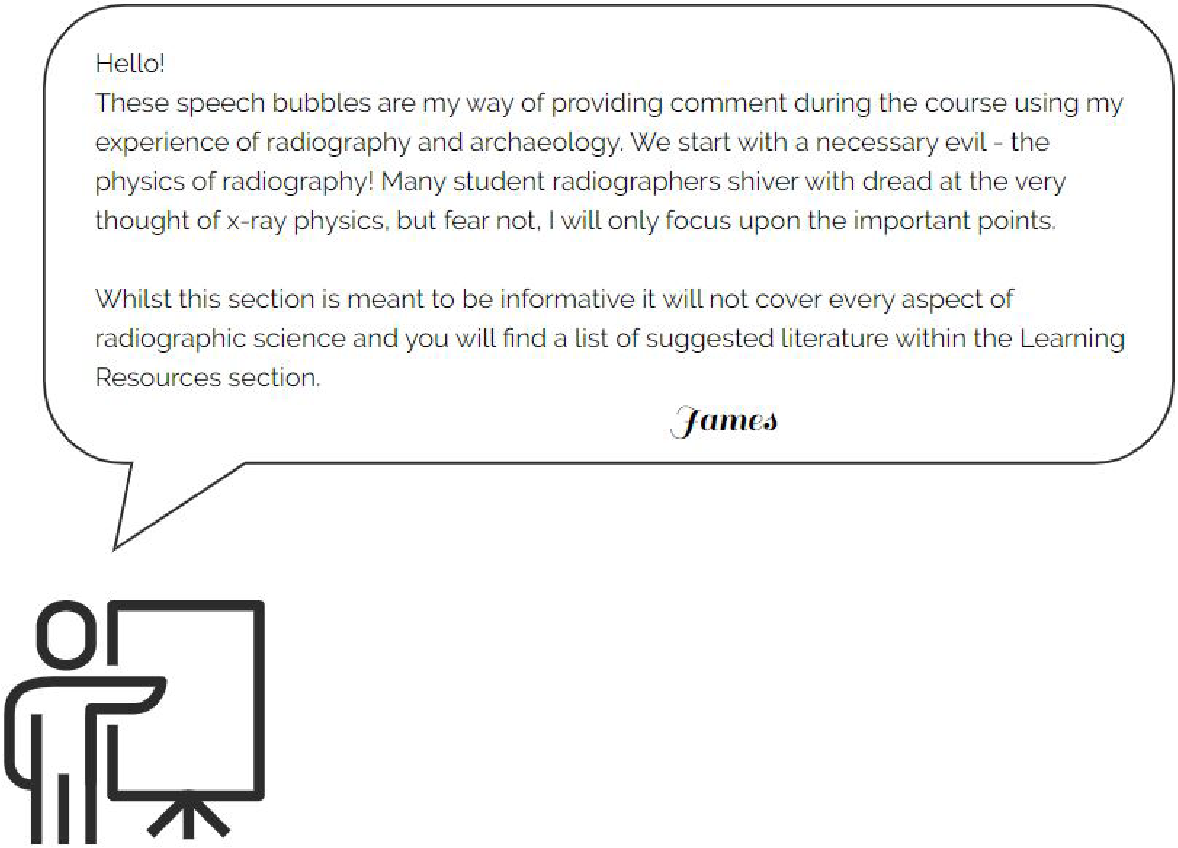


Figure 4. Speech bubbles as a way to integrate personality into the course.

Course Content

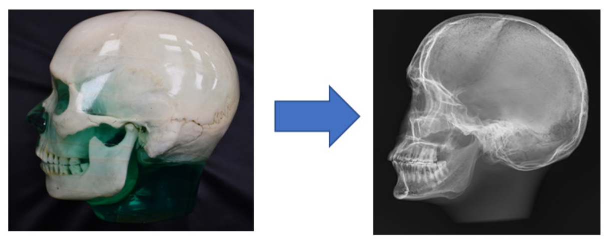
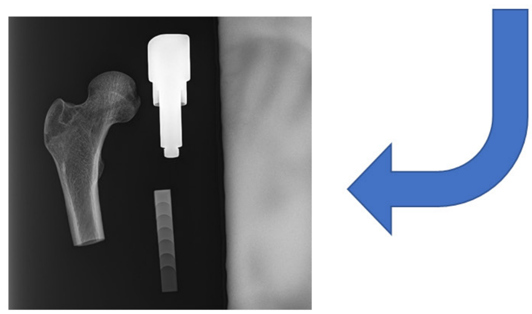
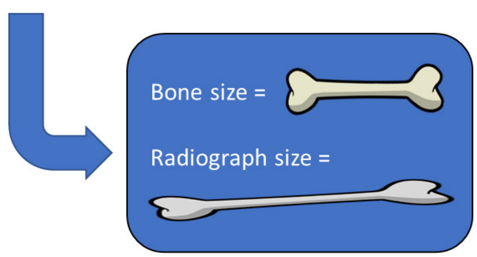
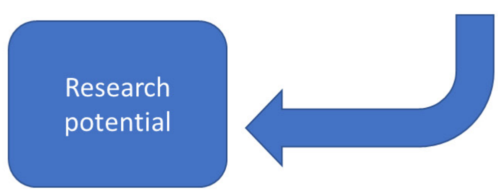
The content of the course was based upon the four threshold concepts listed in Table 1. Each concept acted as a gateway to the next, with progressive comprehension by the participant as demonstrated within Table 2. A graphical representation has been provided alongside the description of each “Aha!” moment as experienced by participants. In the language of the author, the “Aha!” moment is where the participant has understood the threshold concept and moves on to another layer of paleoradiographic theory. The course, therefore, was split into four parts—one for each threshold concept—and each part was designed to require one hour of engagement comprised of:

- 20 minutes of multimedia didactic teaching (text, diagrams, images, video)
- 25 minutes of directed reading (open access academic journals)
- 15 minutes of confirmatory questions and evaluation of the section

Table 1. Threshold concepts within paleoradiography course with webpage titles. Part 2 was later renamed *Image brightness and contrast.*

Threshold concept	Webpage title
1. Radiographs as a two-dimensional representation of a three-dimensional object	Part 1—Core concepts
2. The relationship between specimen density and grayscale upon the radiograph.	Part 2—Image interpretation
3. The effect of geometric unsharpness upon image quality.	Part 3—Radiographic technique
4. The utility of radiographs as a source of quantitative analysis	Part 4—Paleoradiography in research

Table 2. Progressive comprehension of paleoradiography using threshold concepts.

Threshold concept and 'Aha!' moment experienced by participants	Graphical representation
1. **Radiographs as a two-dimensional representation of a three-dimensional object.** Radiographs don't show the 'side' of an object (like photography), they visualize everything at once. X-rays pass through all of the object and therefore the radiograph depicts its entirety.	
2. **The relationship between specimen density and grayscale upon the radiograph.** The amount of 'whiteness' on a radiograph is proportional to its density. However, the radiograph depicts a three-dimensional object with a collective density, not the density of that particular area or anatomical structure. We can measure the 'whiteness' to estimate density.	
3. **The effect of geometric unsharpness upon image quality.** How the object is positioned for a radiograph directly influences the quality of the image. Any portion of an object that is further from the image detector undergoes magnification, making radiographic measurements inaccurate.	
4. **The utility of radiographs as a source of quantitative analysis.** Radiographs can be used to generate measurements of density and dimension, but these must take into account the first three threshold concepts.	

Data Collection

Participants were granted access to the course webpages for one month after providing personal details including age and gender (both optional), place of study (university, country), and year of study. Participant demographics were collected to assess external validity and potential trends in student preferences for online learning. Manual enrollment by the author allowed vetting of eligibility on a case-by-case basis (unlike automated systems). The *Observe* phase of this study involved collection of quantitative and qualitative feedback from the participants, with specific commentary sought for three criteria: learning content, quality, and presentation. Participants were provided with an explanation of each criterion to guide their feedback (Table 3). While free-text responses were optional, a Likert scale to assess each criterion from poor to excellent was mandatory for successful submission of feedback. All feedback was anonymous.

Table 3. Explanation of feedback criteria provided to participants.

Feedback criteria	Explanation
Learning content	Learning content relates to the type and range of information provided to the participant.
Quality	Quality relates to the accuracy of teaching content and level of information taught. It also relates to the mechanics of the webpage, spelling, grammar, and punctuation errors.
Presentation	Presentation relates to the use of text, images, diagrams, and videos as teaching aids.

Results

Participant Demographics

The course attracted considerable international interest with both cycles of the research recruiting to target within six days of advertisement on each occasion. One hundred participants from nine countries and 22 unique universities joined, although only 52% (n=52) completed the course and received a certificate (Table 4). The majority of participants were from the United Kingdom (45%), Canada (28%), and Australia (14%), with the greatest diversity in university institutions from the United Kingdom (n=9). Cycle 2 was dominated by British participants, however both cycles demonstrated substantial diversity with eight countries in Cycle 1 and six in Cycle 2 (Figure 5). Proportionally, Canada had the highest course completion rate per participant for the top three countries (61% of Canadian participants, n=17). The exact program of study was not captured during enrollment, however a variety of pure and mixed archaeology degrees were encountered.

Participants were predominantly female across both cycles (58%), with other participants identifying as male (16%), nonbinary (2%) or preferring not to say (24%).

The average age was 25.7 across all participants, ranging from 18–64 years old, and had a standard deviation of 8.76 (24 abstained from providing an age). The undergraduate year of study was highly variable (Figure 6), although most were within their second or third year (35% and 26%, respectively). A portion of participants stated being in their fourth (12%) or fifth (3%) year of study, with one individual failing to disclose their year of study. Participant demographics were remarkably similar between cycles of the research, with only a slight increase of first year students in Cycle 2 (+10%, n=5), along with a greater number preferring not to reveal their gender (+12%, n=6).

Table 4. Distribution of participants across countries, unique universities and quantity of course completions.

Country of study	Number of participants	Unique universities	Course completions	Completion rate per country (%)
United Kingdom	45	9	22	49
Canada	28	3	17	61
Australia	14	3	6	43
South Africa	4	1	1	25
Norway	3	1	2	67
Italy	2	2	0	0
Spain	2	1	2	100
Colombia	1	1	1	100
United States of America	1	1	1	100
Total	**100**	**22**	**52**	

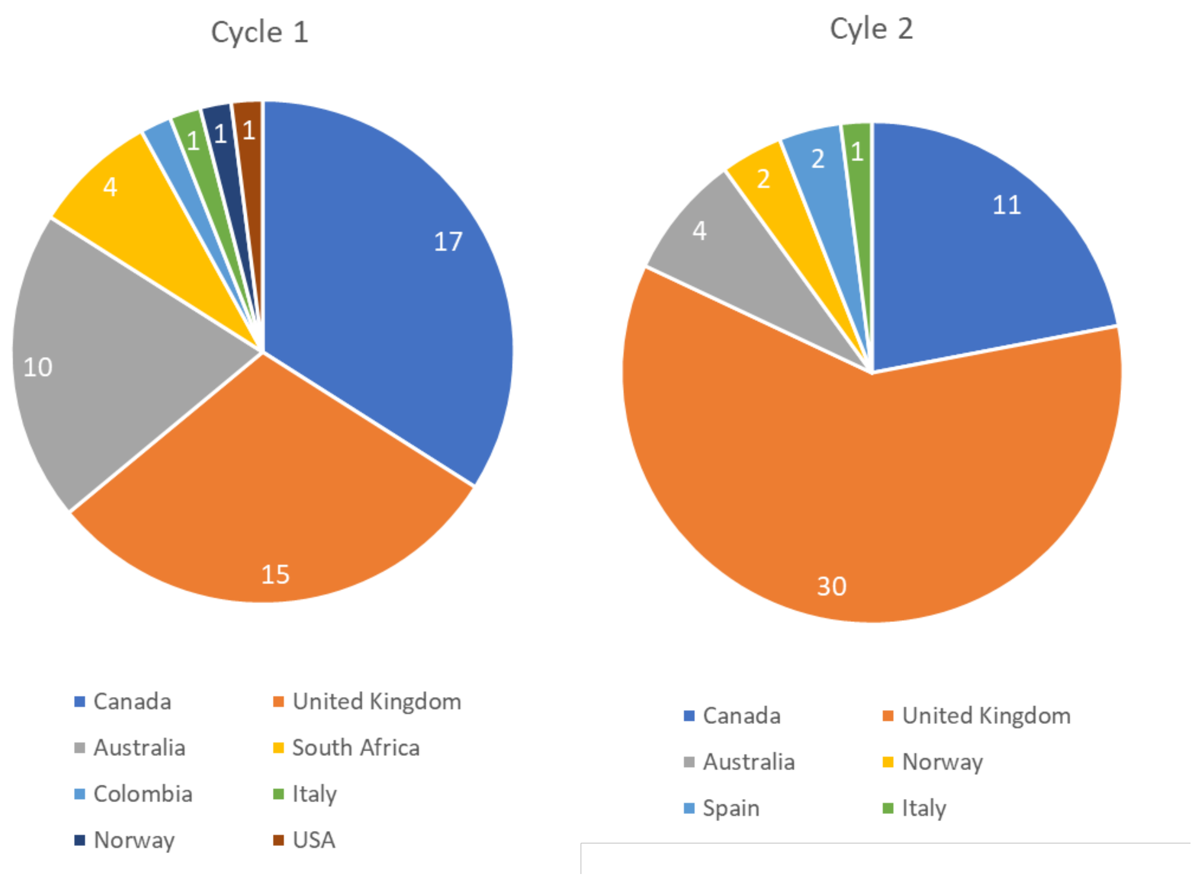


Figure 5. Participant geographical location and quantity per cycle of research.

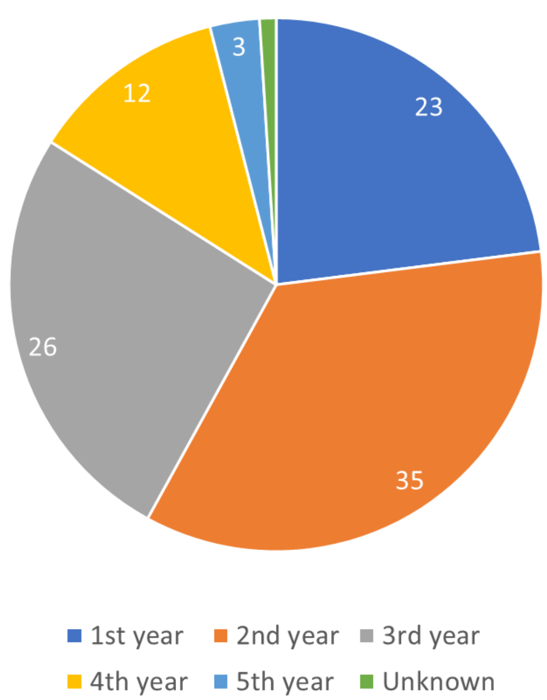


Figure 6. Year of study across both research cycles.

Participant Engagement

Within the first cycle 27 participants completed the course, with a further 25 in Cycle 2. The average time for completion was 25 days after enrollment, with a range of 1–31 days and a standard deviation of 6.48. Within this study, more second-year students completed the course than their peers (35%, n=18), though they were also slightly more numerous within the cohort. In comparison, 13 third-year students (25%) and 9 first-year students (17%) completed the course. It was not possible to quantify how much time each participant spent viewing the website, although some reported taking more than an hour per section (due to the optional reading lists) and one individual appeared to complete it within minutes of enrollment. Table 5 presents the demographics of non-completing participants, providing data on gender, age, and year of study. First-year students showed particularly poor engagement, as did those who abstained from providing age or gender. No significant correlations between age and course completion were seen.

Table 5. Demographics of non-completing participants (ignoring geographical location).

Demographic		Cycle 1	Cycle 2	Combined
Gender	Male	3	3	6
	Female	14	11	25
	Nonbinary	0	2	2
	Prefer not to say	6	9	15
Age	Average years old	26.5	23.7	25.1
	Prefer not to say	7	10	17
Year of study (undergraduate)	First	5	11	16
	Second	7	6	13
	Third	7	6	13
	Fourth	3	1	4
	Fifth	1	0	1
	Unknown	0	1	1

Participant Feedback

The Likert scale feedback for learning content, quality, and presentation are shown in Table 6. The course consistently scored "Very good" across all criteria, however there were progressively fewer responses for later sections of the course across both cycles, presumably due to participant attrition. Nevertheless, average scores were comparable between cycles of the research, with ±0.1 difference in scores for most criteria, and only one section changing by +0.3 for quality (Part 3). The lowest score given was two ("Fair") for learning content, quality, and presentation (in Part 2), which was isolated to one participant who described the explanation of radiographic science as "excessive."

Free-text feedback was prolific, with 150 submissions in Cycle 1 and 103 in Cycle 2. As with the Likert score submissions, there were also progressively fewer free-text submissions for the later parts of the course. Thematic analysis for each cycle of the course has been collated in Table 7, with notable quotes provided in Appendix 1. Three major themes were identified: amount and level of information, praise (generic or specific), and problems encountered.

Table 6. Average Likert scores for course design criteria per section across both cycles. Ranging from 1 = Poor, 2 = Fair, 3 = Good, 4 = Very good, 5 = Excellent.

Number of participant responses: Cycle 1 (blue), Cycle 2 (red).

Part 2 was later renamed *Image brightness and contrast.*

Section of course	Learning content	Quality	Presentation
Part 1—Core concepts (33/29)	4.6	4.5	4.6
Part 2—Image interpretation (33/27)	4.4	4.4	4.4
Part 3—Radiographic technique (29/24)	4.7	4.6	4.6
Part 4—Paleoradiography in research (25/23)	4.7	4.7	4.7
Average score	4.6	4.6	4.6

Table 7. Thematic analysis of free-text feedback across both cycles.

	Theme
Level and amount of information	The course had the correct level of information There was the correct amount of information More information / content requested
Praise	General praise (nonspecific) Images / diagrams Videos Choice of literature for readings
Problems encountered	Issues with videos Criticism of website layout Issues with mobile device version

Observations from the First Cycle

Within the first cycle of research, the participants expressed high levels of praise, but there were requests for more information, images, and videos across all sections. Participants frequently made unique requests for improvement on course minutia, such as image size or labelling. There were also common requests for a simpler explanation of x-ray generation, and greater explanation for photodensitometry (density estimation) and dental aging. Several critical issues were identified: an inability to access the course navigation buttons on smaller screens and some video editing faults. Feedback indicated that the course was suitable for undergraduate students, but perhaps more so for those in their first year due to the limited detail of some learning content. In keeping with the ethos of action research, a list of actionable changes were created and implemented for Cycle 2 (Table 8). These were broadly divided into design-specific changes (course delivery or website construction) and content-specific changes (additional learning resources or information, and amendments to preexisting content).

Table 8. Actionable changes identified during the first cycle (in no particular order).

Design-specific changes
Spelling or grammar mistakes Ability to make images larger (photographs, radiographs) Remove or amend overly complicated diagrams Greater use of videos Re-edit videos to remove dead air and transition problems Break up heavy text or space out with other media Greater color on webpages Add discussion forum for more participant interaction
Content-specific changes
Add an introductory video with the instructor (author) Greater interactivity for the quizzes Avoid excessive repetition of key phrases or information Include photographs alongside radiographs of the same object Greater clarification on specific concepts (with images, video or diagrams) Comparison with other technologies (computed tomography, x-ray fluorescence) Greater inclusivity of global differences in archaeological practice More open access articles and case studies across all sections

Observations from the Second Cycle

A complete overhaul of the website ensued, including optimization for mobile devices and redesign of the navigation buttons (Figure 7). A nuanced change of name for Part 2 from *Image interpretation* to *Image brightness and contrast* occurred to avoid confusion with interpretation of radiographs solely for bone pathologies and trauma. Additional learning materials, including YouTube videos, were sought and integrated alongside a new website discussion forum. A video of the instructor (author) was created and placed at the start of the course to provide a personal introduction and explanation of the course learning objectives. Areas deemed to be lacking detail were fleshed out with greater explanation, bespoke diagrams, and open access literature. The resulting feedback maintained high praise and resulted in substantially fewer requests for additional content. Key feedback for further improvements included even more media (diagrams, images, video), subtitles or transcripts for videos, and conversion to a sequential website design instead of the one-page layout. Of interest was the total lack of engagement with the discussion board for paleoradiography conversation and several requests for warnings for the disturbing content and imagery of some literature (in particular, see Notman et al. 1987). Some technical problems persisted, with video errors occurring on mobile devices and a request for more color to avoid screen glare.

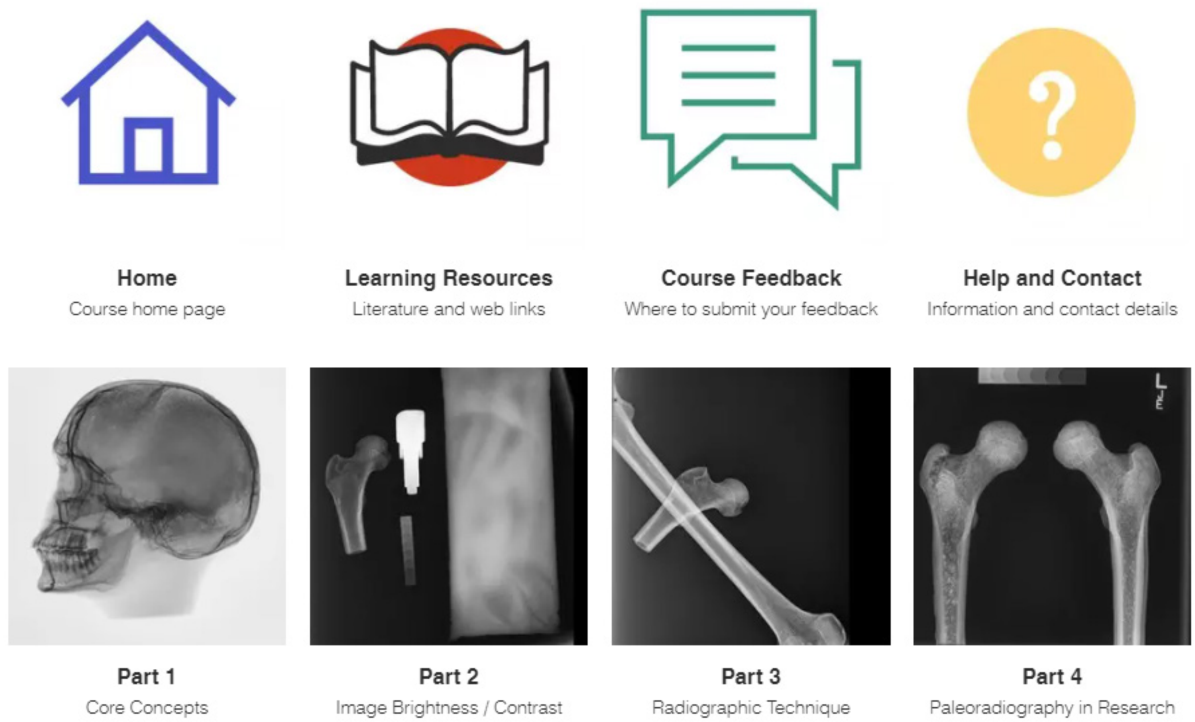


Figure 7. Navigation buttons implemented for the second cycle of the course. The buttons were interactive, inverting in color when hovered over.

Discussion

Teaching Paleoradiography at the Undergraduate Level

At an elemental level this study provides evidence that students have sufficient interest to join a free online paleoradiography course. Furthermore, the demographics of the course suggest a preference by young females across all year groups wishing to learn about the specialized topic. One limitation was the small sample size, however the repeated enrollment of participants between cycles served to confirm these cohort characteristics.

The content and style of the course was designed to be at an undergraduate level but with the delicate task of blending two distinct and seemingly unrelated disciplines: archaeology and radiographic science. The introduction of threshold concepts was meant to bridge that gap, allowing the participant to progressively comprehend the complexities of radiography and appreciate the research possibilities in archaeology. It became apparent that participant expectations for the course were for pathological interpretation of bone radiographs, not radiographic science. Although an important area of teaching, this topic has been addressed elsewhere in archaeology (see Chhem and Brothwell 2008) and already benefits from a vast quantity of clinical radiology literature. In contrast, paleoradiographic theory addresses the fundamental concepts at the point of image acquisition, explaining contributing factors for varying quality and appearances. A solution used by the author was to make the course learning objectives explicitly clear while also sourcing suitable literature to satisfy specific curiosities.

One participant highlighted the lack of hands-on interaction in the e-learning course which is typically expected during on-campus undergraduate archaeology education (Peuramaki-Brown et al. 2020). By its very nature, online teaching encounters challenges quite unlike classroom environments and perhaps the two cannot be directly compared. The lack of tactile experiences associated with e-learning may therefore represent an insurmountable obstacle for this course but highlights the need for adequate management of participant expectations once again. Unlike the rapid transition to e-learning by higher education due to the coronavirus (Watermeyer et al. 2021), this course was afforded the luxury of time and preparation. The advantages of multiple media platforms (photographs, radiographs, video, and text) were exploited to offset the lack of physical contact and optimize the use of screen learning. A post-COVID world might entail a blended approach to paleoradiography, where classroom demonstrations go hand-in-hand with e-learning to improve comprehension and student satisfaction.

Educators who wish to create their own online course should not underestimate the time commitment involved. The first iteration took more than 150 hours over a three-month period, although the second iteration required considerably less time. Where possible, a team approach is advised to share the burden, tackle problem-solving, and foster idea generation.

Measures of Success

The paleoradiography course received considerable international interest but completion rates were relatively low (52%). Similar noncompletion issues were experienced by Alcock, Dufton, and Durusu-Tanrıöver (2016) with only 10.2% of 18,921 and 16.5% of 12,370 students completing their archaeology MOOC in cohorts in 2013 and 2014. In contrast, the Masters-level SPOC concerning digital archaeology reported by Scherjon, Romanowska, and Lambers (2019) had higher rates of completion (29/34 students, 76.5%). This was potentially due to the involvement of fees and the associated attribution of educational credit which offered greater incentive. Noncompletion and student attrition are widely recognized issues within online courses and a major concern for higher education with regard to financial viability (Bawa 2016; Shaw, Burrus, and Ferguson 2016). The factors contributing to dropout rates in free courses are diverse, with Goopio and Cheung (2020) listing learning experience, interactivity, course design, use of web technology, time commitment, and personal learning situations (among others) all influencing completion rates.

A tentative correlation can be made between noncompletion and both those in their first year of study and participants who are reluctant to provide their age or gender. While the former may be explained with overeager behavior or underdeveloped time-management skills, the latter could hypothetically relate to a noncommittal attitude. Further research is required, with a recommendation that online training providers be mindful of these at-risk groups. While it is not possible to ascertain why the participants of this course did not all complete it, there has been sufficient feedback to effect positive change and, therefore, an arguably successful outcome. Indeed, the quantity of free-text feedback was substantial considering the sample size, with an abundance of original and reasoned suggestions for improvement.

The high Likert scores for learning content, quality, and presentation were positive but should be tempered with caution. The recognition that a free course was designed by a fellow student (albeit completing a teaching qualification) and delivered with a personal approach may have induced familiarity or in-group bias and therefore favorable feedback. A potential solution is presented by Borch, Sandvoll, and Risør (2020) who focus upon dialogue-based evaluation methods. In commenting, the participants engage with feedback on a personal level, whether by interview or free-text submission. The free-text feedback of this action research provided a contextual richness far exceeding the blunt answers of the Likert scale. This author is therefore inclined to agree with the use of personal feedback for online or in-person courses for this reason.

Design-Specific Considerations

The Community of Inquiry approach, adapted for e-learning by Garrison, Anderson, and Archer (2000) and advocated by Peuramaki-Brown and colleagues (2020) within archaeology, gives three key presences for e-learning success: teaching, social/emotional, and cognitive. The teaching presence relates to design, facilitation, and direction of learning while social and emotional presence provides the projection of *real* people as opposed to faceless instructors. Lastly, cognitive presence relates to the extent students can construct and confirm knowledge of the subject, typically by assessments or other academic tasks. These shall be considered each in turn.

Teaching Presence. The creation of the course was bound by two limiting factors: the investigator's experience of online course design and the capabilities of the Wix.com platform. Though the risk of the former was somewhat negated by diligent pedagogic research, the latter was truly trial and error with substantial consumption of how-to videos on YouTube. The course presented itself with a quasi-SPOC identity: restricted access with low participant numbers, lacking a true affiliation with a higher education institution, and offering niche market training. Without an association with a formal teaching institution, the course avoided the accessibility legislation of the host nation[1] and could “go rogue.” Nevertheless, consideration must be given to the four terms which underpin accessibility: perceivable (providing alternative formats), operable (navigated by alternative means), understandable (clear, consistent language and navigation), and robust (facilitates assistive technology).

Given that the investigator had never used Wix.com to design and operate an online course before, it is somewhat understandable that the course had flaws within its first iteration. The two critical issues of webpage navigation and incompatibility with mobile devices posed the greatest threat to accessibility and were prioritized for amendment. Further provision of audio versions of on-screen text and transcripts or subtitles to videos may provide alternative formats for learning and improved accessibility. A crucial factor for successful engagement appeared to be the use of a widescreen format by the end user for ease of navigation. In this respect, the Wix.com website design engine offers considerable exploitation of widescreen viewing, but at the expense of those viewing the course on smaller screens. While there are prompts and guides for small-screen compatibility within the Wix.com interface, the enormity of media and functionalities offered often make this difficult to find. Interestingly, of the 100 participants, only a handful remarked on the cumbersome nature of the “one-page” webpage layout. Despite the overall acceptance of the webpage layout, by omission of commentary, a conversion to sequential webpages may improve course navigation and reduce logistical challenges for content management. From a practical perspective, it is easier to amend or update a smaller webpage than a large one.

Social/Emotional Presence. The paleoradiography course initially lacked options for community engagement, which led to subsequent requests for discussion boards and greater visibility of the instructor during videos (i.e., presenting rather than narrating). Both were provided in Cycle 2 but, although the introductory video was praised, the discussion forum was not used extensively by the participants. A potential reason may have been a lack of familiarity with a discussion forum or low perceived value to such interactions. Alternative options for social interaction include Twitter, Facebook or Instagram, which have all been used successfully in higher education (Ahern, Feller, and Nagle 2016; Bista 2015; Carpenter et al. 2020; Tang and Hew 2017). Specifically, Twitter has often been integrated as a means of communication for questions, course updates, and interaction with classmates, as extolled by Bista (2015). The ability to submit short tweets may increase social presence with the tutor in an asynchronous course. Furthermore, social media platforms are actively encouraged by Wix.com for improved connectivity. Such implementations would elevate the course from a Web 1.0 level (static content, no external input) to Web 2.0 with interactive content (Kujur and Chhetri 2015), but then runs the risk of additional management time burdens and possible antisocial behavior. Such risks may be counterbalanced by increased completion rates associated with inter-participant discussion during free e-learning (Wang and Baker 2015).

Cognitive Presence. Although this study did not formally assess comprehension of threshold concepts in paleoradiography, this was an important component of course design. Simple self-test questions were created but were met with requests for greater complexity and interactivity. Previous research suggests that sophistication or gamification of learning content can increase student motivation and engagement (Ross et al. 2018; Subhash and Cudney 2018). Such provisions in this paleoradiography course were limited by the author's ability and awareness of website design, however the second iteration incorporated a quiz engine with greater interactivity. Despite the quiz questions being largely the same, there were no further requests for changes to the quizzes except for their physical placement on the webpage. The added option of downloadable completion certificates for individual quizzes could improve student accountability, providing evidence of engagement and at least a superficial indication of understanding. A written assignment would undoubtedly improve the website's cognitive presence but was beyond the requirements of this e-learning course and the expectations of its participants.

The cognitive presence within this course raises a dilemma: is it an academic course for undergraduates or a learning resource for professional development? Without formal assessment—at an undergraduate level—the answer is the latter. But the use of undergraduate pedagogy may alienate audiences unaccustomed to such teaching content, specifically academic journals. The most likely future for the course, as a SPOC, may therefore require adaptation for general consumption.

Content-Specific Considerations

A benefit of action research is the ability to offer a partnership in learning as a collaborative approach and reciprocal process (Cook-Sather, Bovill, and Felten 2014). The partnership between the subject expert and participants was symbiotic, generating specific requests for development. Feedback concerning content was mixed, with conflicting views of appropriate complexity and quantity of material. Generally speaking, participants sought less information regarding radiographic science and greater archaeology content. This feedback may appear contradictory, given that each participant actively chose to learn about paleo*radiography*, but nevertheless demonstrates preferences for content. Likewise, without being aware of preexisting knowledge of physics and biology, the explanation of simple terminologies or concepts was necessary but may have frustrated a portion of participants.

Feedback for radiation physics and radiographic science was sometimes rather superficial ("diagram too confusing") but archaeological suggestions were abounding.

Requests were made for information regarding radiographic appearances of trauma and pathology along with greater instructional guidance for quantitative methods including photogrammetry, radiogrammetry, and age estimation methods. Such topics, while wholly welcome, fell outside of the introductory level for the threshold concepts and any further expansion may have encroached upon the validated four hours for participant engagement. An interesting development was the specific request for greater inclusion of global archaeological practices, hinting at recent complex debates on decolonizing the curriculum in higher education (Morreira et al. 2020). An elementary solution for future versions of the course may involve submissions of archaeological literature or media by participants. Local sites, or those of personal interest, would therefore be represented rather than those limited to the investigator's awareness.

Dishonesty, Suspicion, and Fear of Missing Out

An unexpected outcome of the study was an insight into online social behavior. Despite clearly outlined requirements for participation, an equal number of individuals requested access to the course that were college staff, postgraduate students or not studying archaeology at all. Unfortunately, access could not be granted to maintain purity of the feedback data. In most instances potential participants readily provided their university email address, a requirement for the enrollment process, but some did not. When pressed, they either admitted to not meeting the requirements of the study or ceased communication altogether. For those who had institutional email accounts but were neither archaeology nor undergraduate students, a reluctance to divulge this information was apparent. Such deception was infrequent but disconcerting. One participant made accusations of repeated phone calls and requests for payment. Upon investigation, it transpired they had independently registered for website hosting using a domain name similar to the course webpage! The bizarre and baffling behavior of society will continue to surprise and entertain the author of this study.

Limitations

Several limitations have already been addressed. There is the potential bias for positive Likert scale results due to the status of the investigator as a fellow student. There is also the inability to assess comprehension of threshold concepts due to constraints of the course design. Other limitations include the extent to which the sample is representative of undergraduate archaeology students as a whole. Advertisement of the course was dependent upon locating suitable email addresses through a search engine (a highly subjective technique) and then the generosity of those recipients who forwarded course details to their students. Furthermore, those that decided to partake in an online course already demonstrated sufficient digital literacy along with the interest to enroll. This suggests the study sample represents the fortunate, capable few rather than the diverse whole. To some extent this explains instances of bias as echoed within the archaeology

MOOC by Alcock, Dufton, and Durusu-Tanrıöver (2016). Lastly, not all participants were studying pure archaeology, with various mixtures with anthropology, classics or heritage. Whether any of this significantly alters the outcomes of this research is difficult to ascertain and may benefit from further research.

Conclusion

Published examples of teaching paleoradiography at an undergraduate level are lacking, despite its value within heritage conservation and archaeological investigation. The results of this action research study demonstrated international interest for a free, short, e-learning course designed and delivered on a Wix.com website. Although the sample size was relatively small (n=100), there was considerable diversity, with archaeology students joining from 22 unique universities across nine countries. Participants were predominantly female, within their mid-twenties, and from a variety of year groups of study. Establishing a definitive demographic for paleoradiography interest was not possible though, partly due to the haphazard sample selection process and partly due to a bias towards computer-literate participants.

The true value of this research was the generation of specific feedback for course design and content by free-text responses. In contrast, the overwhelmingly positive Likert scale feedback was treated with skepticism as a method of evaluation. Perhaps in keeping with their chosen discipline, participants made requests for greater archaeological examples to illustrate the applications of radiography. The careful selection and integration of open access literature, alongside the creation of bespoke diagrams and videos, largely ameliorated these requests for a more comprehensive course. Critical issues identified through course development included robust webpage navigation, compatibility across devices, and the importance of alternative formats for information. Interestingly, the initial outcry for greater inter-participant interaction via a discussion board was met with an absence of engagement by the second cohort. It is unclear why this occurred but use of common social media platforms may provide greater success given student familiarity with them. A notable success of the study was the ability to foster a partnership in learning through an action research approach.

Notes

1 Within the United Kingdom, all higher education institutions abide by The Public Sector Bodies (Websites and Mobile Applications) Accessibility Regulations 2018 (SI 2018/852). Four terms are used to establish accessibility by users of websites and mobile devices (perceivable, operable, understandable, and robust).

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Appendix 1. Notable quotes from free-text responses (in no particular order).

First cycle of the course

“I really liked the way this was organized, the summaries highlighting key points were very helpful and the sections were all clear and flowed into each other well.”

“The videos are very informative and are useful teaching aids. They bring together the concepts of the different parts really well and I’m very glad they are there because they break up the content into different styles which makes it more approachable.”

“I don’t think the course content was too basic for an intro course to the study of radiography, but it might be a little basic for a second- or third-year course meant to come after an intro course on the topic.”

“I really like the overall aesthetics. Simple but captivating. I find myself wanting to read what is in each section, rather than being forced to.”

“The course has broadened my understanding of the techniques and has given me an idea of how I could use these techniques during my studies or potential excavations once I graduated.”

“The only downside is that it was not very physically engaging as in there was nothing else to do other than notetaking and watching the videos. I understand that something like that would be hard to do over an online course, though, so that’s no fault of yours.”

“Perhaps a Q&A section might be added to the end of each section or the course, for further questions to be answered? Rather like a blog, that other participants can see and interact with.”

Second cycle of the course

“The content was good and at a level I understood. However, the imagery is not very appealing. Everything is black and white (I know, like an x ray).”

“I liked the use of symbols (i.e., book for readings) as it made it clear and easy to understand what the task was for that point in the section.”

“One thing that brought elevation was the self-tape videos and personal comments. It didn’t feel like it was just another day in an online classroom; you were there in the flesh teaching us.”

“The way I saw the course was that it was like an ice cream cone. It was extensive at the beginning of each part—giving general ideas and basic concepts. But, in the end, it is focused on the central area of study, paleoradiography and its connection to archaeology.”

“The scrolling of the webpage made it somewhat awkward for reading, as well as remembering your location in the course if you have to step away for a longer period of time.”

“The only aspect I found challenging was the x-ray tube physics, I thought it was slightly too detailed and I occasionally struggled to understand (that is without a background in physics).”

“I particularly enjoyed the video demonstrations of the different ways in which we can position specimens and their effect on image distortion.”

“Overall, the learning content was just right and I think the discussion on x-ray fluorescence and computed tomography was a very positive point as it allowed a more holistic view of how x-rays are used in archaeology.”