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Bones at Home: Supporting haptic learning and universal design beyond the biological anthropology laboratory

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Abstract

Remote teaching during the COVID-19 pandemic led to a range of pedagogical challenges for anthropology laboratory courses. In biological anthropology courses such as Human Osteology, hands-on experience is essential to achieving learning outcomes, including basic bone and feature (i.e., landmark) identification, identification from fragmentary remains, and age and sex estimation. To address the need for training that includes object-based, tactile (haptic) learning in fields such as biological anthropology and archaeology, all Human Osteology students at Mount Royal University and the University of Manitoba took home plastic model skeletons. The purpose of this study was to evaluate how well remotely educated undergraduates (REU) met human osteology learning objectives when supported by plastic model skeletons at home. We present the results of a survey designed to test core osteological skills obtained by REUs in comparison with undergraduates educated with in-person laboratory components (IPU), and experts in the field (0-4 and 5+ years of experience). REU scores did not differ significantly from those of IPU or Junior Experts with less than 5 years of experience. Students performed well in bone identification but were limited in their ability to apply common sex and age estimation methods and to identify incomplete elements. Our findings reinforce the importance of haptic learning and years of experience in human osteological learning. They support the use of take-home models as valuable resources in both remote and in-person undergraduate teaching. This work is a step toward more inclusive universal instructional design that can be applied across various anthropology laboratory courses.

Keywords

Human Osteology; Bioarchaeology; Universal Design; Laboratory Pedagogy; Object-Based Learning; Online Teaching; COVID-19 Instruction

Introduction

Human osteology involves the study of human skeletal remains and is foundational to biological anthropology education, including bioarchaeological and forensic anthropological applications. Undergraduate training in this field typically focuses on anatomical identification (e.g., of a bone, feature, or side of the body a bone is from) and the application of osteological techniques, such as those used to estimate biological sex and age at death. Practical experience is a key part of this learning process, with most traditional courses involving in-person laboratory time to examine human skeletonized remains. The shift to remote teaching in response to the COVID-19 pandemic created a range of pedagogical challenges for anthropological instruction that relies on laboratory demonstration and object-based learning (a pedagogical approach that "emphasizes direct interaction with physical objects" Pollalis et al. 2018:627). However, when taught remotely and/or online, hands-on courses such as human osteology must overcome specific challenges to maintain an environment that facilitates the learning and topic mastery of fundamental hands-on skills.

Virtual technologies that provide a realistic three-dimensional (3D) rendering of bones, artifacts, and excavations are used by many anthropology instructors, especially following their emergency transitions to remote instruction during the COVID-19 pandemic (Spiros et al. 2022; Thompson et al. 2020; Ekengren et al. 2021). Three-dimensional and virtual approaches are readily available resources, and educators are beginning to explore and quantify learning outcomes when digital resources are used instead of in-person examples (e.g., Kuzminsky et al. 2020; Pollalis et al. 2018). However, virtual technologies are not without their challenges and limitations. In archaeological applications, Pollalis et al. (2018) indicate that although their participants achieved good learning outcomes in the analysis of Egyptian sculptures, they often experienced discomfort (e.g., headaches, eye strain) using the augmented reality (AR) headset. Others, such as Ekengren and colleagues (2021), observed that 3D lithics were more easily understood by students once they had first observed the artifact in person, noting issues of scale and the loading time required for images as limiting factors in the use of and interpretation from 3D images. Garstki et al. (2019) used 3D site reconstructions to teach students excavation methods, commenting positively on the flexibility of virtual approaches and their capacity to increase interest in the field. However, they also noted that the haptic (touch-based) experience that is typically important to archaeological instruction is absent in a virtual approach (e.g., students do not learn to "feel how the soil consistency changes when a trowel scrapes from cultural feature to sterile soil" Garstki et al. 2019:57).

Such tactile experience is similarly essential for training in biological anthropology and human osteology. The direct handling of skeletonized remains is often used to reinforce memorization of landmarks and features; the feel of a skeletal feature seems to help students with identification and interpretive assessments (Kuzminsky et al. 2020). For example, being able to feel the size, spread, and area of certain features may help learners to score them on a scale for sex estimation. Similar observations have been made in anatomy contexts where learners focus on osteological features to improve diagnostic abilities through surface (skin) palpation (Giffin et al. 2013). This multi-sensory focus on fine osteological details also prepares students for the identification of incomplete and fragmentary human skeletal remains, which is a requisite skill set for practitioners in as diverse fields as bioarchaeology, palaeoanthropology, and forensic anthropology. The need to include tactile investigation in human osteological learning is reinforced by reports that virtual technologies (e.g., 3D digital models) can be a "less reliable training tool" (Kuzminsky et al. 2020:275). Specifically, Kuzminsky et al. (2020) found that although virtual resources were useful replacements for experienced researchers, student performance in cranial sex estimation using a 3D model was markedly reduced. Additionally, anatomy education research frequently reports that learning stereoscopically, from actual models/remains, significantly improves learning outcomes compared to both 2D and 3D digital/virtual methods (Khot et al. 2013; Viswasom and Jobby 2017; Wainman et al. 2018, 2020).

The current study builds on previous work exploring accessible pedagogical practices in human osteology, such as the use of virtual resources in biological anthropology, anatomy, and archaeology (e.g., Kuzminsky et al. 2020; Pollalis et al. 2018; Wainman et al. 2018, 2020), and earlier examples of using take-home bones in anatomical learning (e.g., Raubenheimer et al. 2019). We propose that at-home materials be integrated into the instruction of anthropological methods to address the need for object-based, haptic learning in fields such as biological anthropology and archaeology. The use of replica human skeletal remains as take-home resources in human osteology was examined by evaluating the skills and techniques developed by students in a remote learning environment. This study therefore aimed to assess the strengths and limitations associated with learning human osteology when laboratory modules are offered in non-traditional ways (i.e., remote instruction, take-home replicas). Research into the efficacy of such tools for training in human osteology is also critical given the range of ethical and curatorial issues surrounding human skeletal remains that frequently form the basis of teaching collections (Caffell and Jakob 2019; Lambert and Walker 2018). We therefore assessed knowledge outcomes of human osteology students whose first exposure to the subject was through the non-traditional remote learning approach using a plastic model skeleton that they took home for the term. We compared these remotely-educated students (REU) to undergraduate students who were educated with in-person laboratory components (IPU), as well as experts in the field (divided into Junior Experts with less than 5 years [E0-4] and Senior Experts with at least 5 years [E5+] of human osteological experience). In order to meet the criteria of expert, an undergraduate degree was required; Junior Experts were graduate students and instructors, whereas Senior Experts were predominantly faculty, post-doctoral researchers, or professional sector employees (e.g., contract archaeology firm employees). These expert groups also captured people who were trained in a more traditional setting involving in-person laboratory-based learning using real human skeletal remains and without take-home resources.

The effectiveness of the skeleton models in assisting students with learning human osteology in a remote (virtually taught) context was evaluated by testing participants on their recollection and identification of important morphological features/landmarks of human bone and on their ability to apply basic osteological techniques (e.g., sex estimation based on morphological features). We hypothesized that at-home, hands-on resources used to supplement anthropology laboratory courses could support and facilitate student learning in courses taught both remotely and in person. This research will enable anthropology laboratory educators to make informed decisions about their resources and deliveries by highlighting core benefits and shortcomings of educational designs that rely on model skeletons rather than real skeletal remains. The mechanisms proposed here can also contribute to more diverse, ethical, accessible, and equitable pedagogical approaches for improved student learning outcomes.

Materials and Methods

The COVID-19 pandemic meant that many higher-education institutions globally were required to pivot rapidly to entirely remote instructional approaches. In order to replicate the tactile experience students would otherwise have with on-campus delivery, plastic skeleton models were obtained in 2020 for instruction at Mount Royal University (MRU, Calgary, Alberta) and the University of Manitoba (UofM, Winnipeg, Manitoba) in Canada. Each institution purchased different skeleton model brands: MRU from hBARSCI (Eisco Labs models, n=31) and UofM from Candent (3B Scientific models, n=24); UofM supplemented their take-home kits with disarticulating skulls from Candent (3B Scientific models, n=24).

In each year of this study (2021-2023), one model kit was loaned to each student enrolled in human osteology courses at MRU and UofM; students took these models home for the duration of the course. Class enrollments ranged between 24 (UofM) and 30 (MRU) students. In 2021, students at both institutions were instructed remotely; in 2022, UofM was online and MRU was in person; both institutions taught human osteology in person in 2023. Each human osteology course proceeded according to instructor design and covered the same core topics (see Supplementary Material A for structure of topics and lecture/laboratory time). Students at MRU received a 2 hours and 50 minute lecture plus two 1 hour and 20 minute laboratory sessions (total weekly contact hours at MRU were 5 hours and 30 minutes), whereas students at the UofM received 2 hours and 45 minutes of combined lecture and lab instruction, plus an optional one hour of weekly open laboratory time. In an effort to closely approximate a typical class setting, remote courses at both institutions delivered synchronous online lectures and laboratories on human anatomy and other osteological themes.

Approximately one week after the completion and grade finalization for each course offering, students were invited via email and the respective university learning management systems to participate anonymously and voluntarily in a skill-testing survey designed and administered remotely using Google Forms (MRU Institutional License). Ethics approval for this study was granted by the Mount Royal University (Application Number 102482) and the University of Manitoba (R2-2021:043 [HS24870]) Human Research Ethics Boards. A series of reminder emails were sent out with the aim of improving response rates, and surveys were kept open for an extended period of time (1 to 2 months). Students were not offered further incentive in order to maintain the integrity of the anonymous survey. Questionnaires could be completed in a location of the participant's choosing, and were not timed or monitored; participants were instructed not to consult additional resources and to base their answers solely on their own abilities. This survey tested their knowledge using photographs of real human bones in varying states of preservation/completeness. Students had gained familiarity with photograph-based assessment using online testing systems through their remotely delivered courses (2021 and 2022), and so the survey mode was familiar to them. While photographic assessment of remains does not replicate direct evaluation of physical remains, basic identification of bones and traits depicted in two-dimensions (e.g., photographs, X-Rays, illustrations) is nevertheless a fundamental osteological skill. This survey was designed to be low-pressure and was administered after grades were completed; students did not earn points or credit from the survey toward their final course grade.

In-person laboratory instruction resumed in 2022 at MRU and 2023 at UofM. Undergraduate students who completed the Human Osteology course in this format (In Person Educated Undergraduate: IPU) were invited to participate in this study. This included access to all the typical bioanthropology laboratory resources, but also taking home a model skeleton for the entire term. To evaluate the effects of different instructional modes on skill acquisition, we compared these in-person educated undergraduates with both remotely educated undergraduates and in-person educated Junior and Senior Experts. The comparative sample of expert osteologists, all with undergraduate degrees or higher, were recruited through an academic poster presentation at the *Canadian Association for Biological Anthropology (CABA-ACAB)* annual meeting (October 2021) and social media advertising (Twitter and Facebook). Experts were divided into Junior Experts with 0 to 4 years of experience (E0-4) and Senior Experts with over 5 years of self-reported experience (E5+). This grouping was established to approximate those with undergraduate to early graduate level experience (i.e., 0-4 years) who may be most comparable to our undergraduate students, versus those with more experience than an undergraduate could typically accrue in a 4-year-degree program (i.e., 5+ years). Earlier cohorts of students who were instructed in-person at MRU and UofM were not surveyed out of concern that the time elapsed since they learned osteology would impact their skill retention and recall. The same survey was distributed to all participants, who were asked to identify specific bones, sides, and/or morphological features, and to apply standard osteological methods for sex and age estimation (see Figure 1 for example questions).

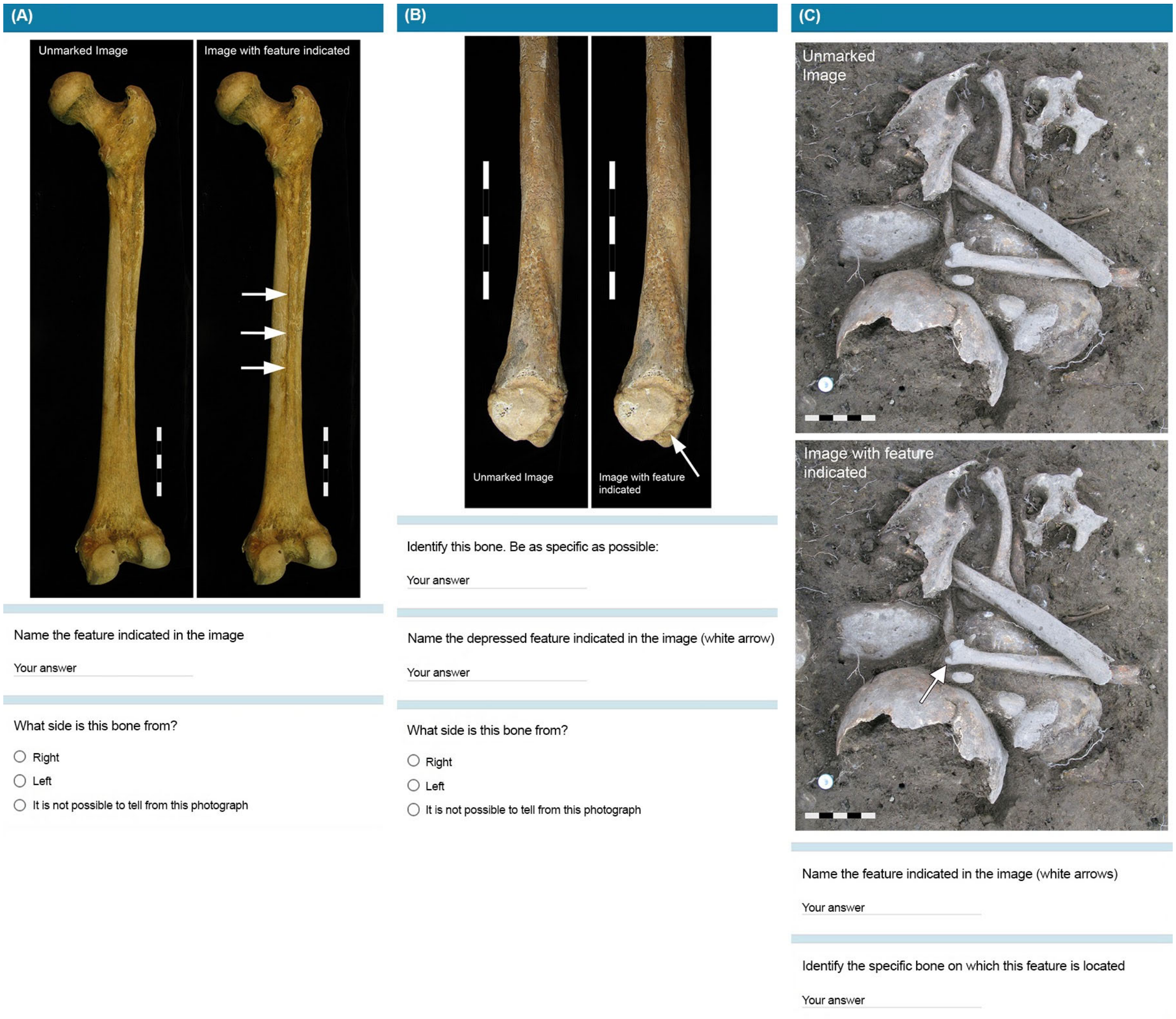

Figure 1: Sample questions from the human osteology skill testing questionnaire. The ability to apply osteological skills to bones in different views and states of preservation was tested through the use of diverse images depicting complete (Image A), partial (Image B), and fragmentary and/or in situ human remains (Image C).

The skill-testing survey consisted of 30 images and a total of 66 questions and evaluated aspects of the entire skeletal anatomy based on the terms and features outlined in White and Folkens (2005). Each survey question included a digital photograph of a skeletal element. Images of real skeletal elements were used to ensure that the knowledge translated well from virtual/plastic model learning to recognition of traits on actual bone. Participants were asked to identify from memory a bone or a specific feature indicated with a clearly marked arrow or box and to respond in the blank space provided. Other questions asked participants to select the bone side or the sex or age category that best described the remains from a list of options. Survey questions were distributed evenly across the bones of the human body and five body regions (i.e., upper limb, lower limb, thorax/shoulder, skull, and pelvis) and were evaluated using a series of six images each (Table 1).

Six sex estimation questions using the skull and pelvic girdle were included (four males and two females, with the sex imbalance due to image constraints). At least one image that represented clear male or female morphology was included for both sexually dimorphic regions. All individuals examined in this survey were considered to be adults; no non-adults with completely unfused epiphyses were included in the questionnaire images. Age-related questions asked participants to evaluate a line of fusion in a second metacarpal, a forming flake at the medial clavicle, and to apply the Suchey-Brooks (Brooks and Suchey 1990) and Lovejoy et al. (1985) methods for pubic symphysis and auricular surface age estimation, respectively. Question images were also selected to represent remains that were complete, partial, and either fragmentary or *in situ* (still in the soil in an archaeological context) in order to explore how the condition and preservation of remains influenced observer skill (Table 2). A total of 46.7% (n=14/30) of the question images represented complete bones, 36.7% of question images were partial views of bones, and 16.7% captured bones that were incompletely represented in some way.

Table 1: The number of questions designed to test different osteological skills, divided by body region.

Question Categories	**Skull**	**Upper limb**	**Thorax/ Shoulder**	**Pelvic girdle**	**Lower limb**	**Grand TOTAL**
Bone identification	4	5	5	2	4	20
Feature identification	6	4	6	5	4	25
Side identification	1	3	1	1	4	10
Sex estimation	3	0	0	3	0	6
Age estimation	0	1	1	3	0	5
Total	14	13	13	14	12	66

Table 2: The number of questions and clarification of how they were designed to test osteological skills on remains of varying degrees of completeness and/or preservation.

Preservation	**Sub-Question Count**	**Description of Image Attributes**
Complete	27	Entire skeletal element is present in the image in a typical view (e.g., anterior, posterior, medial, lateral).
Partial	27	Part of the skeletal element is visible in the image (e.g., the proximal half of a humerus), and/or some images are presented in less-typical angles (e.g., oblique medial view of the clavicle).
Fragment	12	The skeletal element is incomplete or fragmentary with some missing and absent portions and/or the skeletal element is presented *in-situ* in an archaeological excavation context with some aspects of the element not visible.
Total	66	

Additional contextual questions were asked, including whether the participant had learned osteology remotely or in person, using real or model human remains, the level of education involving osteology (e.g., undergraduate, masters, doctoral, postdoctoral, other), their current career, occupation, or educational status (undergraduate student, masters student, doctoral student, postdoctoral researcher, faculty, professional sector, other), and number of years practicing human osteology. Reflective questions and Likert scale questions concerning the learner's experiences of using a take-home skeleton model were asked to contextualize the quantitative survey results. The Likert questions asked participants to self-assess their confidence in identifying human bones, morphological features, bone side, sex, and age on a scale of 1 to 5. Undergraduates were also asked to reflect on how the take home model helped them to learn these variables and to rate their overall experience using the five point scale. Specifically, these open questions asked students to elaborate, using examples, the 'role that your take home model skeleton played in learning how to identify human bones, morphological features, and bone side…' and (separately) for learning how to estimate age and sex. A final question invited participants to leave any additional comments they might have. These qualitative responses were used to provide context and student voices to our results, but the analyses and interpretations in this research are derived from the quantitative data collected through the knowledge-based questions.

A strict binary approach was adopted to score survey responses; only completely correct answers earned a point (scored as correct [1] or incorrect [0]). For example, an image depicting a first metatarsal that asked for a *specific* bone identification was only given a point for the answer 'first metatarsal'. Survey responses were discussed by both RJG and JAG to ensure agreement in responses and across institutions. Some poor spelling was permitted if it was very clear what the participant meant. For example, "coastal groove" was accepted in place of costal groove. Each component of a multi-part question (such as a series of questions asking for bone, feature, and side identifications from a single image) were marked separately (i.e. one point was awarded for each question for a total of three points in the above example). Any answers left blank were considered incorrect.

SPSS (Version 28, Windows) was used to compare the survey scores among and between REUs and IPUs at MRU and UofM, Junior Experts (E0-4), and Senior Experts (E5+). Data were not normally distributed within all variables so nonparametric statistics were used for all comparisons. Survey reliability was tested using Cronbach's alpha (α), a measure that indicates response consistency within a survey tool. MRU and UofM scores were evaluated using a Mann Whitney U test. For each group of respondents, the relationship between confidence in their skills and their total survey score was evaluated using Spearman's correlation coefficient. REU, IPU, E0-4, and E5+ scores were compared using Kruskal Wallis tests with Dunn's pairwise post-hoc tests adjusted with Bonferroni corrections. Results were considered significant at a level of $p \leq .05$. Open-ended responses were evaluated using QDA Miner Lite v.2.0.9 where student responses were coded according to perception of how well the skeletal model helped with identification (of bone side, feature, and element), with sex and age estimation, and according to sensory reflection (observation on physical manipulation of the bone, placement of the bone in relation to the skeleton or self, feature visibility). Since this was not a qualitative study, analysis of open-ended question responses was conducted with the goal of gaining narrative insight into the quantitative results rather than as a formalized qualitative analysis.

Results

Fifteen remotely educated (REU) and 12 in person educated (IPU) undergraduate students at MRU and UofM completed the survey between 2021 and 2023 (Table 3). Response rate was low, with an average of 16.7% of students completing the survey over the 3 years (MRU: Winter 2021, 2022, 2023, Fall 2023; and UofM Winter 2021 and Fall 2022). However, as no significant difference was present in the overall survey scores between MRU and UofM (U = 78.0, p = .749), these groups were combined as the 'Remotely-Educated Undergraduate' (REU) and 'In Person Educated Undergraduate' (IPU) samples for analyses. Twenty-one 'experts' participated with seven having between 0 and 4 years of experience (E0-4) and 14 having 5 or more years of experience (E5+). The survey (66 graded questions, completed by 48 participants) showed a high level of internal consistency among question responses in our sample (α = .904).

Table 3 - Participant counts, the number of respondents: remotely-educated undergraduates (by university), in-person educated undergraduates; and Junior and Senior experts (based on years of experience).

		Experience		**Grand Total**
		0-4 years	**5+ years**	
Remotely Educated Undergraduate	MRU	8	-	8
	UofM	7	-	7
	REU Total	15	-	15
In Person Educated Undergraduate	MRU	9	-	9
	UofM	3	-	3
	IPU Total	12	-	12
Expert	Faculty/Teaching	3	4	7
	Graduate Student	4	5	9
	Postdoctoral & Professional Sector	0	4	4
	Unknown	0	1	1
	Expert Total	7	14	21
Grand Total		34	14	48

REU = Remotely Educated Undergraduate; IPU = In Person Educated Undergraduate.

Average total survey score, scores for each skill category (bone, feature, side identification, and sex and age estimation), and correct assessment (of complete, partial, or fragmentary bones), were compared among the four experience groups. The undergraduate and E0-4 survey participants had an average confidence in their abilities of between 3.5 and 3.8 on a scale of 5; the E5+ participants had increased confidence of 4.3, on average (Table 4). Participant confidence and total scores were poorly correlated for undergraduates and E0-4; E5+'s confidence and total scores were highly correlated. Survey scores differed significantly among surveyed groups in all attributes, except for feature identification, and sex and age estimation (Table 4; Figure 2). Pairwise comparisons revealed no significant differences between REU, IPU, and E0-4 in any examined attribute, suggesting that the skill level of undergraduates, regardless of their education mode, is comparable to that of the Junior Experts (i.e., those with less than 5 years of experience).

Pairwise post hoc tests (conducted only on categories found to be significantly different with the Kruskal Wallis tests) identified significant differences between REU and E5+ in all remaining categories (bone and side identification, and complete, partial, and fragmentary categories), indicating that people with 5 or more years of experience generally demonstrated greater osteological knowledge than REUs. When IPU and E5+ were compared, the significance disappeared in two areas (complete and partial bones), suggesting the difference in these average scores was reduced between IPU and E5+. Together with the other findings, these results indicate a slight improvement in IPU abilities, albeit not so large as to result in significant differences between IPU and REU groups.

Table 4 - Raw and percent survey scores averaged by sample (REU, IPU, E0-4, and E5+) and organized by question skill category.

Skill Category	N Questions per category*	Average Scores (%) REU Average (%)	IPU Average (%)	E0-4 Average (%)	E5+ Average (%)	Kruskal Wallis REU vs. IPU vs E0-4 vs E5+
Confidence						
Average Confidence	-	3.6 ± 0.6	3.5 ± 0.7	3.8 ± 0.5	4.3 ± 0.6	**H = 10.326 (3), p = .016**
Correlation between confidence and total score		*r*=.459, *p*=.085	*r*=.401, *p*=.197	*r*=.486, *p*=.269	***r*=.710, *p*=.004**	**-**
Category						
Bone identification	20	61.3 ± 12.5	53.3 ± 10.9	75.0 ± 17.8	88.2 ± 13.4	**H = 24.987 (3), p < .001**
Feature identification	25	56.3 ± 23.8	63.0 ± 14.3	56.6 ± 19.1	72.6 ± 21.5	H = 7.714 (3), p = .052
Side identification	10	54.7 ± 18.1	59.2 ± 20.2	62.9 ± 25.0	82.9 ± 16.4	**H = 13.228 (3), p = .004**
Sex estimation	6	65.6 ± 18.3	61.1 ± 22.8	66.7 ± 23.6	66.7 ± 16.0	H = 1.031 (3), p = .794
Age estimation	5	41.3 ± 24.5	61.7 ± 24.8	54.3 ± 22.3	54.3 ± 16.5	H = 6.404 (3), p = .094
Preservation						
Complete	27	64.9 ± 15.1	68.2 ± 13.7	69.8 ± 21.2	81.7 ± 12.3	**H = 10.631 (3), p = .014**
Partial	27	57.8 ± 15.9	62.7 ± 12.9	65.1 ± 17.4	74.1 ± 15.7	**H = 9.881 (3), p = .020**
Fragment	12	38.9 ± 23.5	31.3 ± 16.3	47.6 ± 20.8	72.6 ± 20.0	**H = 18.833 (3), p < .000**
Total						
Total	66	57.3 ± 14.4	59.2 ± 12.4	63.9 ± 17.4	76.9 ± 14.2	**H = 15.063 (2), p = .002**

REU = Remotely Educated Undergraduate; IPU = In Person Educated Undergraduate; E0-4 = Junior Experts with less than 5 years of experience; E5+ = Senior Experts with 5 or more years of experience. *Note that a single question image may represent multiple categories.

**See Table 5 for pairwise post-hoc tests.

Table 5 - Posthoc Dunn tests for the significant Kruskall Wallis tests reported in Table 4. Significance values adjusted by the Bonferroni correction for multiple tests. Pairwise post-hoc tests were not performed if the initial Kruskal Wallis test was not significant (i.e., sex and age).

	Confidence	Bone ID	Side ID	Complete	Partial	Fragment	Total
REU vs. IPU	1.000	1.000	1.000	1.000	1.000	1.000	1.000
REU vs. E0-4	1.000	.580	1.000	1.000	1.000	1.000	1.000
IPU vs E0-4	1.000	.080	1.000	1.000	1.000	1.000	1.000
REU vs E5+	.069	**.001**	**.004**	**.013**	**.018**	**.003**	**.003**
IPU vs. E5+	**.019**	**.000**	**.040**	.078	.117	**.001**	**.009**
E0-4 vs. E5+	1.000	1.000	.417	.778	1.000	.253	.349

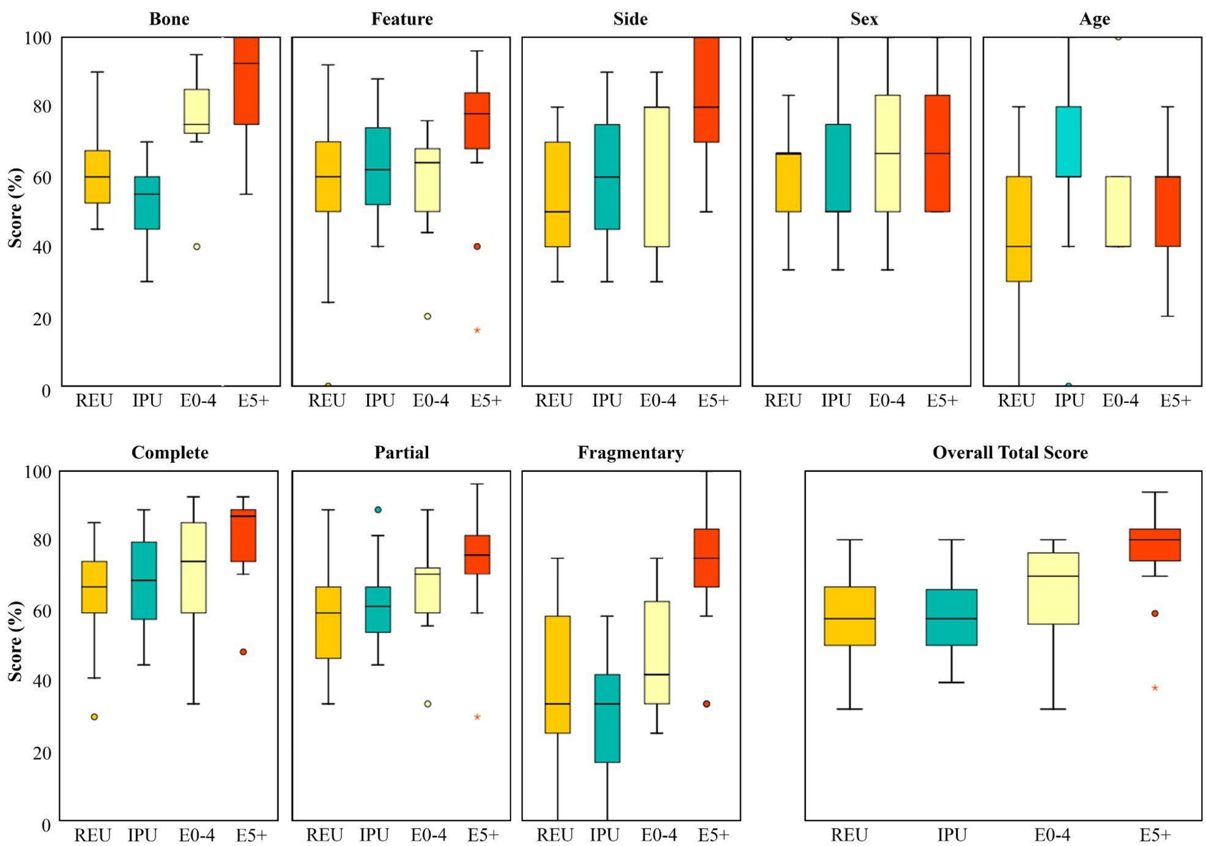

Figure 2: Box plots comparing the scores (in percentages) by skill category and overall total among remotely educated undergraduates (REU), in person educated undergraduates (IPU), Junior Experts with undergraduate degrees and less than 5 years of experience (E0-4), and Senior Experts with undergraduate degrees and 5 or more years of experience (E5+). The y-axis reports total score in percent, no upper error bars are possible above the perfect score of 100%.

The ability of participants to identify osteological attributes correctly in incomplete remains and to apply age and sex estimation techniques showed interesting patterning. The difference in the average score between REU/IPU and E5+ is smaller for complete than it is for fragmentary remains. Although the experts still routinely performed better than the undergraduates on all types of remains, between REU and E5+, there is only an average 16.8% difference in their scores for complete bone identification, compared to a 33.7% difference in their performance on fragmentary bone identification; this difference is comparable for IPU and E5+ at 13.5% (complete) and 41.3% (fragmentary). E5+ are clearly better at examining fragmentary remains than novice undergraduates, although they are more similar in their ability to identify complete remains. Unexpectedly, none of the tested groups demonstrated significantly different scores associated with estimating age and sex from the digital photographs and resources provided in this survey. This result might reflect limitations posed by assessment from photographic images that may not sufficiently capture important attributes on real remains, such as surface texture, shape, and topographic relief. Future studies should consider re-evaluating these skills using real remains in an in-person setting.

The open-ended questions added further context by highlighting key patterns in the ways students found their model skeletons to be useful (see Supplementary Material B for full responses). REUs identified benefits for bone and feature identification (each noted by 40.0% of respondents), as well as side identification (noted by 73.3% of respondents). Feature identification was also a characteristic highlighted by 58.3% of IPU respondents. REUs also appreciated the ability to physically manipulate and to orient bones in relation to themselves or other bones (53.3% and 46.7% of respondents, respectively), but this was slightly less prominent for IPU respondents (41.7% in both cases). REU (26.7%) and IPU (25.0%) respondents valued the 3D and stereoscopic benefits of working with the model skeletons. On the other hand, students did note limitations, commenting specifically on difficulties associated with a lack of feature definition on the models (20.0% of REU and 25.0% of IPU respondents).

Students generally found model skeletons to be more useful for learning sex than age estimation. Forty percent of REU and 33.3% of IPU respondents commented that they found the model skeleton somewhat useful for learning sex estimation techniques, while 33.3% of REUs specifically noted that they did not find it at all useful for this purpose. REUs who found it somewhat useful for this noted benefits for recognising some of the core features used in sex estimation, but also noted that one model provided insufficient exposure to the range of trait expression (20.0% of REUs). On the other hand, fewer respondents (6.7% of REUs and 8.3% of IPUs) found the model skeleton useful for age estimation, while 73.3% of REUs commented that it was not at all useful or that it was more challenging to use to learn to estimate age. Half of IPU students noted that they did not use their models at all for either sex or age estimation (this may be explained by availability of real human skeletal remains during in-person laboratory time). REU students in particular reported a lack of feature expression with the models being overly smooth, inhibiting their ability to score key traits used for age estimation (40.0% of respondents).

Discussion

In response to the remote-instruction required during the COVID-19 pandemic, many anthropologists adopted a wide variety of approaches to laboratory instruction ranging from entirely virtual to take-home resources. Previous research on virtual learning in biological anthropology found that digital 3D models have limited efficacy for teaching novice students cranial traits used in sex estimation (Kuzminsky et al. 2020). Students of gross anatomy also performed better when learning from physical models and real human remains than from digital ones (whether 2D or 3D) (Wainman et al. 2018, 2020; Yammine and Violato 2016). In an effort to overcome these limitations during a challenging time in education, we integrated take-home model skeletons in our online-instruction.

Overall, our results showed minimal differences in the scores of students with access to take-home skeletons who were educated remotely versus in-person. The IPUs and REUs with access to take-home model skeletons both performed comparably in bone, feature, and side identification to E0-4s whose education was delivered in-person in the laboratory classroom (one E0-4 respondent reported they were educated in a hybrid manner with some in-person and some online instruction). As IPU and E0-4 both have the same approximate number of years experience (i.e., 0-4), this result is expected. The statistically comparable REU and E0-4 scores may be explained, in part, by the availability of tangible and tactile resources to use at home, helping students who learned at home exclusively with a plastic model skeleton to achieve foundational learning outcomes comparable to individuals (Junior Experts) educated in person.

When undergraduates were compared to E5+ we saw an interesting pattern emerge. E5+s scored higher than IPUs in their total score, bone, side, and fragment identifications, but their scores were not significantly different for complete or partial bone categories, despite being higher on average. In comparison, when REUs were compared to E5+s, we see clear and significant differences in skill levels in almost all areas. We interpret the difference between REUs and IPUs relative to E5+s as a result of greater exposure to a variety of remains and morphologies in laboratory settings and through years of acquired experience (in the case of E5+s). This finding reinforces the critical roles of practice and experience with human remains in training skilled human osteologists. Mastery of the osteological skill sets requires extensive experience with a wide variety of human remains in different states of preservation and trait expression (Caffell and Jakob 2019). It is through this experience that we expect osteological learners to improve their skills the most, a concept that is reinforced by the significant differences identified between the undergraduate and E5+ samples and by student observations to the open-ended questions (comments on their lack of experience with variation were particularly common amongst REUs).

We expected this experience with skeletal variation to be especially important when learning to estimate age and sex osteologically. REUs who used take-home skeleton models also identified this in their reflections, noting the importance of seeing variation and the limitations of only having one model:

> *The plastic skeleton helped me with siding and identifying bones but with only one skeletal example (rather than a few different ones in a regular lab) it was difficult to identify, feel, and visualize variation between skeletons and be able to identify non-ideal/perfect human bones with only one physical example. But definitely still very useful.* (MRU REU Student, 2021)

REUs also observed issues with the level of detail captured by casts, leading to inadequate feature representation in some cases. This was particularly challenging for joint surfaces used for age estimation. For example, one student noted that:

> *I think age estimation was the aspect that was lacking the most with the model skeleton. Most of the surfaces you would use to estimate age were just smooth and didn't have*

> *much characteristic. Sex identification was good and distinguishable.* (UofM REU Student, 2022)

It is clear from student experiences that while the take-home models were useful for learning to identify elements and features, age and sex estimation posed challenges. Beyond the insufficient detail in the casted remains, as noted above, students recognised that the lack of exposure they received to a range of trait expression reflective of normal human variation was a limiting factor in their learning experience. For example, one student observed that:

> *The one thing that was not very helpful about the skeleton is that it was a representation of only one individual, so while we could identify the sex and age of that individual, it was not good for practicing how to identify age and sex on multiple individuals... Age was also harder to estimate on the skeletal model that we had because things like the joint surfaces or articular surfaces were not very clearly depicted in the model as they might have been on real human bones…* (UofM REU Student, 2021)

REUs clearly recognised that experience with only one skeleton left them inadequately prepared to apply osteological sex and age estimation techniques. Both the poor level of detail on some joint surfaces and lack of exposure to the range of human variation may explain, in part, the challenges undergraduates encountered in applying age and sex estimation techniques.

Although we anticipated that the REUs would find sex and age estimation challenging, even with take-home models, the lack of significant differences between undergraduates and both expert levels in these skill categories is surprising. Specifically, the E5+ sample did not perform significantly better than the undergraduates in sex or age estimation. This result might be explained by the methods themselves. The importance of experience in sex and age estimation is broadly recognized in the field (for an overview, see Milner and Boldsen 2012), with more experience generally being linked to greater proficiency in technique application, even with techniques designed to maximize objectivity (Milner and Boldsen 2012). It is also important to consider that any osteological assessment of age and sex should be contextualized in relation to the population-level range of trait expression. That is, the range of trait expression is not universal and the expression for any given trait differs among populations (e.g., Frankenberg 2021; Savall et al. 2016; Spradley et al. 2008; Walker 2005, 2008). Participants in this study were not given any information about the archaeological contexts from which the remains were derived. Additionally, expert respondents highlighted the need to be able to move a bone around to see different views, and also to take a broader scope of features into account for age and sex estimation, and even siding; an approach that could be improved with integration of 3D models in future skill testing assessments:

> *In general some of the side identifications that I found the trickiest were when a feature was photographed directly facing the camera and so it was sometimes hard to tell if something was coming towards or pointing away from the camera (the damaged os coxa and the scapula, for example, I found tricky to side from the pictures).* (Expert, 5-9 years experience)

Working with remains in varying states of completeness and preservation is another skill that expert osteologists (including bioarchaeologists and forensic anthropologists) acquire through experience and time with skeletal remains from different contexts. This is one clear area that we see as a large limitation for REUs using take-home resources. Our results showed that undergraduates performed least well on questions that involved fragmentary remains. Relative to undergraduates, the Junior Experts performed slightly better (though not significantly) and the

Senior Experts with 5+ years were significantly more skilled. This finding again speaks to the necessity of time and experience with remains for mastery of osteological skills. Typically, the take-home resources that are available and affordable consist of complete, disarticulated remains. Students educated using these resources, without access to the osteology laboratory, would not have the opportunity to handle remains in varying states of preservation and fragmentation, and so would not have the chance to practice applying their identification and siding skills to incomplete remains. Evaluating fragmentary remains is a puzzle in three-dimensions, and students often have to think abstractly to imagine where a specific piece best fits in the body. Further familiarity with features and shapes (e.g., cross-sections and profiles) seen in isolation from other features and landmarks can only be gained through direct and extensive exposure to fragmentary remains. While none of the survey respondents specifically addressed the use of models for fragment analysis, REUs did describe their process of analysis:

> *…[The model skeleton] was extremely helpful in studying while doing remote courses because it allowed me to physically rotate, feel and identify the features, it also allowed me to lay out the entire skeleton so I could learn the bones and their features in relation to other bones which was very helpful with siding…* (UofM REU Student, 2021)

> *It helped to be able to have a physical model to arrange the skeleton and view all sides of the individual bones and how they connect together since we couldn't access a lab.* (MRU REU Student, 2021)

This insight from students, combined with the comments from experts regarding sex and age estimation and siding challenges, reinforces the idea of osteological examination taking place in real, hands-on, 3D space. Physical experience with a skeleton appears to play a role in helping students visualize where in the body a bone (and in more advanced cases, a fragment) best fits.

Pedagogical literature within the field of gross-anatomy has examined factors influencing student anatomical learning in 2D, 3D, virtual reality, augmented reality (AR), and in person modalities (e.g., Wainman et al. 2018). Ramkumar et al. (2019) observed similar visual behaviour across 3D prints, 3D virtual models, and AR images when applying eye tracking technology, but noted a particular focus by participants on manipulating models (move, rotate, etc.) in the AR modality, suggesting that the importance of physical manipulation requires further exploration. These findings are in agreement with those of Kuzminsky and colleagues (2020) who investigated the reliability of scoring cranial traits for sex estimation using real bone versus 3D digital models. They found that some cranial traits were more easily scored on real remains than on 3D models, particularly with the novice participant. This suggested that 3D models were poor replacements for real bone when learning osteology as it was not possible to palpate them and they could be poorly represented in 3D space. Furthermore, when anatomy students were surveyed about access to learning materials, Raubenheimer et al. (2019) found that access to human bones via take-home skeletons was preferred by anatomy students when learning human osteology. This study reports that these students predominantly used these resources to learn bone orientations and features (Raubenheimer et al. 2019). Our findings echo this, showing that undergraduates had the greatest success learning bones, features, and sides, and that they report this learning being supported by access to take-home models. As such, much like anatomical applications, it appears that learning directly from physical objects is not only preferred by students but should improve learning outcomes in anthropology laboratory courses.

We therefore suggest that access to take-home resources may serve as a useful tool to support core osteological learning in a way that facilitates tactile experiences (haptic learning) in an environment comfortable to learners and without time limit. These types of take-home, practical laboratory resources have been successfully integrated in other STEM disciplines such as anatomy, chemistry, and mathematics (Balta et al. 2021; Duranczyk and Fayon 2008; Kennepohl 2021), and became more common with mandated remote-learning during the COVID-19 pandemic (Bauler et al. 2022; Spiros et al. 2022; Thompson et al. 2020). Although many of these resources were developed as emergency teaching adaptations, their continued use to augment the in-person classroom holds additional promise for accessibility and universal design, described as "...a model for creating inclusive curricula that are accessible to a larger proportion of students, especially those with disabilities" (Higbee et al. 2008:61). In this study, the IPUs still found the take-home models useful for practice, and one noted that they appreciated being able to take their time with the model skeleton. One MRU IPU (2023) student noted: "i can take my time and look at the bone over and over again". Another stated:

> *"practicing my siding and lecture notes at home was really helpful and i feel as though i would not be as proficient in mu osteology class without it. it was also helpful for reading the textbook and applying the morphological feature descriptions to the physical bones."* (MRU IPU Student, 2023)

Engaging with course content through multiple means of representation, expression, and action are fundamental principles in universal design (Balta et al. 2021; Higbee et al. 2008). Although it requires greater pedagogical innovation and adaptation beyond the introduction of models, the use of these flexible take-home resources can provide students with opportunities to engage with classroom material in a wide variety of ways, while also allowing for individual choice in when, where, and how to learn.

In addition to steps toward accessibility provided by this approach, the integration of take-home resources in anthropological instruction also has potential to address questions surrounding ethical learning from human remains. Ethical concerns surrounding questionable historical sourcing of many osteological collections used for teaching (Lambert and Walker 2018; Nilsson Stutz 2023) have led to a range of responses even prior to the COVID-19 mandated transition. These include a shift away from the use of real skeletonized remains for teaching by some educators. As part of this transition, many are instead relying on digital resources, leading to engagement with questions surrounding the ethical production of 3D virtual models, which thereby extend to the creation and study of model skeletons (see Spiros et al. 2022; Spake et al. 2020). While our results cannot directly address the ethics of learning from real versus model skeletons, they do speak to the role that real human skeletal remains play in supporting the development of essential, more advanced skills (Caffell and Jakob 2019). In particular, these results highlight the need to ensure sufficient exposure to skeletal representations that capture sufficient detail, states of preservation, and scope of human variation to train skilled human osteologists. As such, our results support and emphasize this need for a continued review of skeletal teaching approaches, and the development of ethically-sensitive collections and collection-management strategies to assist advanced learners in acquiring these specialized skill sets (e.g., analysis of fragmentary remains). Further research into 3D, virtual, and augmented reality skeletal models that are ethically produced, accessible to students in relation to technology and connectivity capacity, and that capture a range of human variation and levels of preservation should continue to be considered as complementary instructional aids (Spiros et al. 2022).

In making our interpretations and recommendations, we recognise that our study involves a relatively low response rate relative to overall class enrolment (16.7% of students). This pattern is consistent with declines in course evaluation rates (Avery et al. 2006; Guder and Malliaris 2010; Nulty 2008), and with the phenomenon of survey saturation wherein surveys became particularly common (and overwhelming) through the pandemic (de Koning et al. 2021). Nulty (2008) recommended that students be encouraged to complete evaluations through repeated invitations (though recognising diminishing return), provision of an easy to access link to the survey, use of incentives/rewards, extended availability of the survey, familiarity with the online environment, and assurances of anonymity. Our surveys are in line with these recommendations, but no additional incentives were offered in order to maintain anonymity. Furthermore, it is possible that our results reflect some bias, with particularly dedicated and highly performing students completing the surveys. However, the consistency of results between both institutions, the range of correct/incorrect responses, as well as mixed confidence declarations, supports a reasonable capture of student proficiencies. Finally, we could not control for participant noncompliance in completing the survey without use of reference resources (although clear instruction was provided at the beginning of the survey in an effort to counter this). However, the relatively low scores (especially for undergraduate participants at 58% on average, 77% for E5+) suggest that most respondents completed the survey as instructed.

Implementation of take-home resources in teaching takes time and financial resources, both at the outset and for maintenance. Aspects educators should consider include the initial cost of models, navigating their distribution to and return by students, replacement costs for damaged or lost components, and storage of the models when they are not in use. However, the benefits to students observed through this study strongly advocate for justification of the initial institutional investment. Instructors might also consider a mixed model, where the purchase of a model skeleton by students themselves is offset by low or no cost readings and/or with institution-owned models being available for students to borrow on an equitable, rotating basis. Skeletons comparable to those used in this study can be purchased for between $100 and $200 (CAD) each. The authors of this paper have sent model kits home over a period of 4 years and have not encountered significant issues with their return. However, options for student accountability can be explored in relation to grade release and institutional hold policies.

Our results highlight two recommendations for effective training in human osteology. First, when possible, take-home model skeletons should be incorporated in laboratory teaching as they help provide a firm foundation for learning introductory human osteology through haptic (hands-on) learning and universal design. Integrating take-home models in Human Osteology classes, regardless of delivery mode, has clear and stated benefits to student experience, and can serve as a further tool for accessible learning to meet diverse learner needs. The benefits are encapsulated by one MRU learner, who noted that:

> *Allowing us to use the models is truly something that everyone in Osteology should have access to as there are many differing forms of learning that will benefit each individual separately.… having access to this resource allows for an inclusive learning experience for all learners, accommodating and promoting the success for all types of learners.* (MRU IPU Student, 2023)

Second, this study shows that such models do not offer sufficient support for more advanced training in human osteology, such as that involving human variation and identification from fragmentary remains. Alternative materials (e.g., real human skeletons) that capture greater diversity and varying states of preservation should also be made available to learners (Caffell and Jakob 2019; Kuzminsky et al. 2020).

The next step in contextualizing these results would involve administering the same skill-testing survey to students learning human osteology in person and entirely virtually, but without access to take-home models. This would make it possible to investigate how the osteological skills of remotely-educated undergraduates captured by this study compare to those of students educated in both of these modes, without the added benefit of take-home model skeletons. This approach would test the extent that having these resources augments student learning even when students have regular access to a range of real human skeletal remains, and also the impact on learning without access to a physical skeleton (whether real or replica).

Conclusion

During the COVID-19 pandemic, many laboratory classes pivoted to completely online and virtual instruction. This study found that undergraduates educated remotely demonstrated similar levels of human osteological knowledge to undergraduates educated in person (both groups had access to take-home skeleton models) and Junior Experts with less than 5 years of experience. We believe that the use of take-home model skeletons supports remotely-educated undergraduate students in learning osteology skills, and continues to provide an important accessible resource to undergraduate students educated in person. Remote students demonstrated comparable skills in bone, side, and feature identification, but skill limitations were specifically identified in their ability to estimate age and sex; undergraduates also performed poorly when asked questions based on fragmentary or incomplete bones. These findings are likely reflective of limited exposure to remains of varying morphological expression and preservation.

We suggest that creating opportunities for students to spend more hands-on time with anthropological materials, such as skeletal remains, will help improve their ability to apply techniques, recognize variation, and gain skills necessary for assessing varying states of preservation. Such opportunities present the most effective ways for students to learn the skills needed to identify and assess the range of human osteological remains they might encounter as professional biological anthropologists. At the same time, this research shows that take-home skeletal models have potential to increase laboratory flexibility and accessibility, contributing to the development of universal design approaches in osteological teaching at the novice and undergraduate level. As one MRU (2021) student noted, “having taken [the] course both in person and online, I feel that the skeleton kit would have greatly improved my experience for either delivery. Having access to this resource was a highlight of my degree.” These results have implications for similarly hands-on courses across anthropological subfields, emphasizing how diverse resources and pedagogical practices can engage learners and facilitate skill acquisition in accessible ways.

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Supplementary Material A

Comparison of Human Osteology content themes instructed at Mount Royal University and the University of Manitoba, divided by week of instruction (and lecture versus laboratory, in the case of MRU)*

<table>
<tr><th colspan="2">Mount Royal University*</th><th rowspan="2">University of Manitoba
Lecture + Lab
(2 hours 45 minutes)</th></tr>
<tr><th>Lecture
(2 hours 50 minutes)</th><th>Laboratory
(2 hours 40 minutes)</th></tr>
<tr><td colspan="2">Introduction to the human skeleton, bone biology, anatomical terminology, lab protocol</td><td>Terminology, Ethics, Variation, Anatomical Concepts</td></tr>
<tr><td>Field and excavation procedures</td><td>Skull: Calvarium & Splanchnocranium</td><td>Bone biology</td></tr>
<tr><td>Laboratory procedures</td><td>Skull (Mandible, Maxilla) and dentition</td><td>Finding the bones: identifying and distinguishing human bone</td></tr>
<tr><td>Dentition, introduction to metrics</td><td>Metrics & cranial landmarks</td><td>Dentition, maxilla, mandible</td></tr>
<tr><td>Activity & biomechanics</td><td>Hyoid, vertebrae, thorax</td><td>Cranial vault and sutures</td></tr>
<tr><td>Sex estimation</td><td>Shoulder girdle, arm, hand</td><td>Vertebral column, thorax, shoulder girdle</td></tr>
<tr><td>Growth & development</td><td>Pelvic girdle, leg, foot</td><td>Pelvic girdle, sex, and age estimation</td></tr>
<tr><td>Stature & ancestry</td><td>Age and sex estimation</td><td>Arm, leg, stature estimation</td></tr>
<tr><td>Palaeopathology</td><td>Stature and ancestry estimation</td><td>Hand</td></tr>
<tr><td>Biomolecular methods</td><td>Palaeopathology</td><td>Foot</td></tr>
<tr><td>Bioarchaeological ‘populations’</td><td>Palaeopathology and osteobiography</td><td>Palaeopathology</td></tr>
</table>

*Mount Royal University offers Human Osteology as a 2 hour and 50 minute lecture plus two 1 hour and 20 minute laboratory components; this differs from the University of Manitoba that offers the course as a 2 hour and 45 minute lecture/laboratory combined. Due to the difference in offering style, the content covered in MRU’s lecture is detailed separately from the content covered in the laboratory section. Open laboratory sessions, outside of regularly scheduled class hours are available at UofM, but not at MRU; these open sessions likely help to balance any difference in instructional time between the institutions.

Supplementary Material B

Remotely Educated Undergraduates

Please tell us the role that your take-home model skeleton played in learning how to identify human bones, morphological features, and bone side (examples welcome!).

Mount Royal University	Siding bones is much easier when you have access to both the left and right sides of the body. It helped to be able to have a physical model to arrange the skeleton and view all sides of the individual bones and how they connect together since we couldn't access a lab. By being able to physically analyze my skeleton for as long as I needed, I felt more capable and secure in figuring out the features I struggled with. I could always pick up the bone and just identify its features whenever I was trying to study! The plastic skeleton helped me with siding and identifying bones but with only one skeletal example (rather than a few different ones in a regular lab) it was difficult to identify, feel, and visualize variation between skeletons and be able to identify non-ideal/perfect human bones with only one physical example. But definitely still very useful. the take home skeleton really helped with identifying morphological features. it also helped with siding by being able to hold the bones up to pictures from class. Siding bones from pictures is extremely difficult. I found that having a skeleton at home greatly increased my interest in the course as I was able to study in depth outside of a lab setting. This added study time with 3D objects made information retention much easier. I did not have to stare at photos at length to side them as it had become more intuitive with the at home skeleton. The take home skeleton was extremely useful especially for learning the cranium, hands, and feet. It was also very helpful to help to side bones. Features were fairly difficult to see or feel on the skeleton especially in the depth that we were tested on in lab portions. It was incredibly helpful - there were some discrepancies with small abnormalities in the casting of the bones, but other wise very helpful.
University of Manitoba	it was really nice to have a model especially when it came to siding so you could see/lay on top of your self how the bones fit. It was also really helpful that the models had most of the morphological features. Excellent for putting into perspective anatomical features It helps seeing the bones with the notes in a better perspective! For example, I would look at the slides and try to side based on the photos exclusively (just because the tests are based on photos and videos so I practiced identifying using more photos more) but seeing and having the skeletal models in front helps when I can't seem to identify bones just based on my notes. It also helped me practice since I can use it in relation to me and my anatomical position It allowed me to have a hands on rather than just a virtual learning experience with bones which in-fact made learning about them more fun. I mostly used the model skeleton to match the physical features to the same features that we were shown in images in class and the textbook. This was extremely helpful in studying while doing remote courses because it allowed me to physically rotate, feel and identify the features, it also allowed me to lay out the entire skeleton so I could learn the bones and their features in relation to other bones which was very helpful with siding. For example, because I could line up the auricular surfaces of the os coxa and the sacrum, and knew that the pubis of the os coxa points anterior and medially and is more inferior, that would help me determine the side that the os coxa came from. Also being able to handle the hand and foot phallanges and the metacarpals and metatarsals allowed me to determine the differences to be able to distinguish bones that would look too similar in diagrams. Having the disarticulated skull was also extremely helpful in learning all of the parts of those bones because the small features on the smaller bones were easier to see when I could remove them from the rest of the skull. The skeleton model helped me learn to side bones by holding them up to myself whenever I would forget. It also made drawing the bones for the Lab Manual much easier, and thus I was able to remember better. It was extremely helpful for identifying specific bones. You could orient the bones however you needed to, which was really helpful for identifying and comparing, versus using a picture from your notes for reference. Also it was really helpful for siding and practicing siding.

Please tell us the role that your take-home model skeleton played in learning how to estimate age and sex (examples welcome!).

Mount Royal University	It was less helpful in identifying age and sex because we were never told the age or sex that our skeleton model was supposed to approximate. It was nice to have an actual physical model for sex determination so that we could see a close up of actual features and indicators which may not be as clear on just images I did not use my skeleton much for learning how to estimate age and sex because it did not seem to have great expression of any of the features that are used for those estimates. However, i may have neglected using it because I struggle with age and sex and I just struggle in general fully understanding how to identify these accurately. For sex and age the plastic skeleton only allowed for one physical example but it did help with physically feeling the sex and age estimation features rather than only seeing them in the textbook and on a screen. the take home skeleton played a bigger role in learning sex determination. age was a bit more difficult, it was harder to tell if something was age related or a casting issue. sex was much easier to determine as those features weren't casting problems. I believe that the skeleton provided was varied enough in presentation to show very specific and important features such as the ventral arc. The ambiguous nature of the skeleton also allowed for the student to see a collection of features which, outside of reference material, would not have been found in a single individual (eg. the strong ventral arc on the pubis and strong male characteristics of the skull). This provides contrast between the features as well as a baseline for the variable nature of the human skeleton. The model skeleton was a fairly good reference to look at for bones but in order to compare the skeleton to textbook examples of age and sex it may be more useful to provide a variable age of the take home skeleton. It helped form one side of the 50/50 question when it came to sexing. I do have other experience that helped more with that, but it was useful to some degree.
University of Manitoba	it was a little hard to estimate age and gender since the model as mostly ambiguous for the most part the take home model was not very useful in this aspect, and something that I struggled with in the course I think that the sex for the bones were ambiguous and I can't say I'm confident being able to identify the age. On the other hand, the models helped for sex estimation because I could feel the bump (with the nuchal crest) and just touch the texture I was supposed to look for like the mental eminence and mastoid process! Not all the features were in detail at-least for me in order to identify age The one thing that was not very helpful about the skeleton is that it was a representation of only one individual, so while we could identify the sex and age of that individual, it was not good for practicing how to identify age and sex on multiple individuals, which made studying for the tests a little harder because we had to go off of diagrams for other examples. Age was also harder to estimate on the skeletal model that we had because things like the joint surfaces or articular surfaces were not very clearly depicted in the model as they might have been on real human bones. It was helpful for an example of sex estimation because I could still move the bones around to see the different parts (for example to look at the ishiopubic ramus) and compare to diagrams of already estimated male or female bones, however again it was only helpful in practicing sex estimation on one individual The skeleton model helped a to learn how to determine sex more than age. It made it easier to learn via Remote Learning than it would have to only be able to look at photos, but it was still difficult because I only had one example to study in-person. Age was difficult to determine due to the bones being a model, this not providing a good example. I think age estimation was the aspect that was lacking the most with the model skeleton. Most of the surfaces you would use to estimate age were just smooth and didn't have much characteristic. Sex identification was good and distinguishable.

Please feel free to leave any additional comments below. We would be glad to hear from you!

Mount Royal University	I think that having a take home skeleton would definitely be beneficial for future uses especially during covid and especially for students taking classes related to knowing to knowing the skeleton for the fist time since they wouldn't have access to one from lab otherwise. pictures help being able to see the actual thing in person and maneuver it is always better. For me, it was very useful to have the plastic skeleton for class and I really appreciated the work that went into getting them for us. Thanks. Having taken course both in person and online, I feel that the skeleton kit would have greatly improved my experience for either delivery. Having access to this resource was a highlight of my degree. My results from this may not be useful - I did put this off and forget about it as May is a busy month for me. I really loved this course and having the skeleton at home was very very helpful.
University of Manitoba	overall, I really enjoyed the class! I was anticipating working with real human bones, but the models were a really big help and maybe a little bit better since we are able to take these home and practice/review I miss being in this class! I wish it could be offered longer or more frequent than once a week but nonetheless, I enjoyed it a lot and the experience was great! I also miss my model skeleton, 've grown attach to it and I can't make the joke that I have skeletons in my closet anymore I think the model skeletons were a great alternative to use to learn the bones and the various features and siding when students are not able to be in a lab t study real human bones and I found it extremely helpful to be able to handle the bones on my own time as well while studying. I really enjoyed being able to bring home the model skeletons. It made learning the bones and features easier than it would have been if I did not have them. I recommend using them in future courses, even for in-person courses, because students will be able to look at the model to help remember features/bones.

In Person Educated Undergraduates

Please tell us the role that your take-home model skeleton played in learning how to identify human bones, morphological features, and bone side (examples welcome!).

Mount Royal University	Great for labs in particular when it came to being tested on bones, siding, age, stature and sex estimation techniques. However, it was also a great visual when learning specific features or even sutures to be able to put a name to a physical bone when I would have otherwise only had the textbook I put stickers on the features that I was expected to identify for the quizzes and before each quiz, I went through the bone names/features and siding techniques For tarsal and carpal bones especially I used it to practice identifying, to make accurate q-cards, and practiced constructing the full skeleton it is was helpful for lab quizzes . It is nice to have things that you can see how they can articulate and you can put them together to get the overall picture. the take home model was extremely useful especially for identifying features and learning to side bones, i am very thankful for the opportunity to use the bones for the semester. practicing my siding and lecture notes at home was really helpful and i feel as though i would not be as proficient in mu osteology class without it. it was also helpful for reading the textbook and applying the morphological feature descriptions to the physical bones. Having a hands-on experience from the model kits provides tremendously useful in studying as they provide an experience that cannot be replicated by simple visuals in photos or text descriptions, yet in pairing visual or textual descriptors to what is being seen and held was wonderful. In being able to take home the model, it allowed for a visual and kinetic experience that photos may not be able to replicate or be seen very well such as many of the finer details of bone giving a significantly greater understanding of morphology. Being able to pick up and compare to our own bodies for siding, or laying it out in anatomical position to study siding and identification was also a huge help in assisted understanding. I personally did not use it very much, only twice. Typically used textbook photos as they had more detail.
University of Manitoba	It was extremely helpful for identifying specific bones. You could orient the bones however you needed to, which was really helpful for identifying and comparing, versus using a picture from your notes for reference. Also it was really helpful for siding and practicing siding. I used the model as a final confirmation. I would print off blank sheets and draw lines to the features then I would label them 8-10 times to memorize the names and spelling. Then I would move to the skeleton where it would help cement everything in my mind and provide depth that paper misses. My take-home skeleton helped me learn bones more easily because I was able to articulate them. This helped me learn and understand bone position more. They also helped with siding because I was able to use model skeletons for reference against my own skeleton. The model skeletons also helped with morphological features a great deal, but some features were difficult to identify, particularly small features, such as textured surfaces. The model skeleton was extremely helpful, as the amount of time we spent with bones during class times was not enough to learn all the features. Also, it is not enough to look at pictures while learning bones because you really have to be able to see the bones from all angles and be able to feel the features in order to truly understand where features are and how they relate to one another.

Please tell us the role that your take-home model skeleton played in learning how to estimate age and sex (examples welcome!).

Mount Royal University	It was a great first basis type of standard. However, it also proved challenging as you don't have the vast diversity that could be present so while you would become extremely familiar with your skeletons appearance, it wasn't always helpful in distinguishing other extremes of sex and age estimation features did not use it for sex/age n/a It didn't really using the model and following the textbook, i learnt about the features and how i would do the sex and age estimate. i can take my time and look at the bone over and over again. practicing age and sex on the take home model was very useful for my studies and helped me learn, apply, and practice all of the methods Simply being able to hold and visualize what to look for was very helpful, especially for sex estimation sizing differences such as parts of the skull, or the Greater Sciatic Notch. Using that example specifically, being able to measure with my own hand as a way of sizing, rather than using photos, was incredibly useful in the understanding of sex variation. I personally did not use it very much, only twice. Typically used textbook photos as they had more detail.
University of Manitoba	I think age estimation was the aspect that was lacking the most with the model skeleton. Most of the surfaces you would use to estimate age were just smooth and didn't have much characteristic. Sex identification was good and distinguishable. Same as above. I didn't use my model skeleton to estimate sex or age, so it didn't really help me in this aspect of osteology. I did not spend any time trying to estimate the age or sex of my model skeleton because simply learning all the features took up all my time.

Please feel free to leave any additional comments below. We would be glad to hear from you!

Mount Royal University	I cant imagine learning osteology without access to a skeleton specimen. I learnt a lot from having the take home skeleton I am happy that i got to use the bones and not just rely on pictures. i like to feel things to remember them for quizzes. since i could not write on them. i used sticky notes and label parts of bone. overall it was a good learning experience that helped me to understand the human body better in 3D Allowing us to use the models is truly something that everyone in Osteology should have access to as there are many differing forms of learning that will benefit each individual separately. For visual or kinetic learners, having access to the models is incredibly helpful yet maybe to auditory or other types of learners, it may not be as helpful. In having access to this resource allows for an inclusive learning experience for all learners, accommodating and promoting the success for all types of learners.
University of Manitoba	From 2002 to 2022, this has been a great addition to the learning process. With limited time in the classroom and limited remains, this has been a helpful tool. I would recommend adding take home teeth as well.