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RESEARCH REPORT

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Transforming musculoskeletal anatomy learning with haptic surface painting

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Abstract

Anatomical body painting has traditionally been utilized to support learner engagement and understanding of surface anatomy. Learners apply two-dimensional representations of surface markings directly on to the skin, based on the identification of key landmarks. Esthetically satisfying representations of musculature and viscera can also be created. However, established body painting approaches do not typically address three-dimensional spatial anatomical concepts. Haptic Surface Painting (HSP) is a novel activity, distinct from traditional body painting, and aims to develop learner spatial awareness. The HSP process is underpinned by previous work describing how a Haptico-visual observation and drawing method can support spatial, holistic, and collaborative anatomy learning. In HSP, superficial and underlying musculoskeletal and vascular structures are located haptically by palpation. Transparent colors are then immediately applied to the skin using purposive and cross-contour drawing techniques to produce corresponding visual representations of learner observation and cognition. Undergraduate students at a United Kingdom medical school (n = 7) participated in remote HSP workshops and focus groups. A phenomenological study of learner perspectives identified four themes from semantic qualitative analysis of transcripts: Three-dimensional haptico-visual exploration relating to learner spatial awareness of their own anatomy; cognitive freedom and accessibility provided by a flexible and empowering learning process; altered perspectives of anatomical detail, relationships, and clinical relevance; and delivery and context, relating to curricular integration, session format, and educator guidance. This work expands the pedagogic repertoire of anatomical body painting and has implications for anatomy educators seeking to integrate innovative, engaging, and effective learning approaches for transforming student learning.

KEYWORDS
anatomical illustration, anatomy education, anatomy teaching, gross anatomy, topographic anatomy

Leonard Shapiro and Ella Hobbs contributed equally to the work and should be recognized as joint first authors.

INTRODUCTION

Art-based learning

There is an extensive historical relationship between art and anatomy,[1-4] with these traditions built upon in multiple studies that have explored the value of art-based learning in modern anatomical and medical education. Recent work has identified that art-based learning can positively influence knowledge acquisition and retention,[5-9] and clinical observation.[10-13] While several authors have explored drawing as the principal art-based approach,[5,14,15,16,17,18] educators have also described the creation of anatomical representations using modeling clay.[8,19,20,21,22,23,24] While it is convenient to categorize art-based learning with respect to the practical technique used, a common feature that is likely to be key to the success of all art-based approaches involves the enhancement of learner observational and visualization skills.[18,21] In turn, such skills are likely to be crucial when attempting to understand three-dimensional anatomical structures and relationships.[25-28] For purposes of clarity, it is important to define similar and related descriptive terms with respect to visual and spatial anatomy learning (Table 1).

Anatomical body painting

Body painting involves the application of paint or pigments to the skin and has become increasingly popular in anatomy education during the 21st century.[29] Within this timescale, a clear purpose and basis for the educational usage of body painting has been established. While the continuing popularity of the approach is likely due to learner enjoyment and engagement in the approach,[30-34] and despite findings, which suggest that body painting can support social and tacit learning within the hidden curriculum,[35] the major pedagogic value in body painting is likely to be found within the domain of anatomical observation and visualization.[36,37] Indeed, the embedded elements of color, visual and tactile stimuli within the body painting process have been proposed to influence knowledge retention and recall,[32,34,36] and a deep understanding of spatial anatomy and anatomical variation.[31] Practically, body painting has primarily been utilized in surface anatomy education as a link between anatomy and clinical skills, and as a precursor to clinical examination.[30,38] In this context, body painting exists as a tool used by learners to create visual representations of the dermatomes or surface reflections of underlying structures on the skin, such as the heart, lungs, and abdominal viscera.[29] The positioning of paintings is based on guided learner identification and mapping of bony landmarks, such as the ribs, sternum, and vertebrae, through palpation. Learners also require prior knowledge of the anatomical structures under consideration and appreciation of the positioning of theoretical anatomical boundaries such as the mid-axillary and mid-clavicular lines.[39] While primarily utilized to support abdominal, thoracic, and neurological clinical examinations of human patients, body painting has also been used to represent musculoskeletal and neurovascular structures in both human[29,40] and veterinary[41,42] anatomy. More recently, body painting techniques have been developed and modified to enhance the visual elements of the process. Modern approaches include usage of paint that fluoresces under ultraviolet light,[43,44] and the use of augmented reality to digitally project paintings onto the skin.[45]

Since the onset of the Covid-19 pandemic, the delivery of anatomy education has changed from a primarily laboratory-based discipline to a subject delivered using a variety of blended in-person, synchronous, and asynchronous modalities.[46-49] Pandemic-era issues relating to campus access and physical distancing,[50,51] and the suspension of donor programs[52-54] have forced anatomy departments and medical schools to adapt their traditional practical approaches to include delivery of remote and non-cadaveric anatomy teaching.[46,55,56,57,58] Previous work has identified the importance of haptic learning[18,59,60,61] (Reid et al., 2019)[17] and collaborative small-group activities[16,62,63,64] as effective educational approaches. While a combination of visual, haptic, and social elements is recommended for optimal anatomy learning,[18,25] current trends toward remote delivery are likely to restrict learner social interactions with both peers and educators, and reduce hands-on access to physical cadaveric specimens, anatomical models, and human volunteers acting as body

TABLE 1 Visuospatial anatomical terms and definitions used in this report.

Term	Definition
Anatomical spatial ability	Capacity to rapidly mentally manipulate previously observed and visualized anatomical features and structures, in both two and three dimensions
Anatomical spatial awareness	Cognitive process of applying general principles of three-dimensional spatial concepts for understanding anatomical features and structures
Anatomical visualization	Cognitive process of creating mental representations of real anatomical features and structures. Distinct from "imagination," the cognitive process of creating mental representations of objects or images that do not physically exist
Anatomical visual representations	A physical object or image that describes an anatomical concept, feature, or structure, and which can be explored using the sense of sight
Spatial anatomy skills	Applying anatomical spatial awareness when performing a specific behavior or task, for example, identifying anatomical features, interpreting clinical images, or performing clinical examinations

painting models. Haptic and social aspects of the anatomy laboratory learning environment are unlikely to be comprehensively recreated through implementing common pandemic-era adaptations, such as live streaming of cadavers or increasing access to virtual technology-enhanced resources,[47,51,58] and these remote approaches are likely to continue within postpandemic blended curricula.[49] Consequently, it is necessary to identify remote approaches that can address the haptic and social, as well as the visual, learning of anatomy. When engaging in remote learning, the only accessible resource possessing the physical qualities of anatomical realism is likely to be the living anatomy of the learner. A body painting approach that utilizes this resource and emphasizes palpation and understanding of three-dimensional anatomy may, therefore, be an important addition to the pandemic-era and postpandemic toolbox of the modern anatomy educator.

Musculoskeletal anatomy education

The delivery of musculoskeletal anatomy within medical curricula has recently been reviewed, developed, and adapted,[65-68] with the Delphi panel method having been used to construct core syllabuses specifically for this topic.[69,70] Integration of musculoskeletal anatomy with radiology[71,72] and the use of creative methods[73] and virtual reality[74] have also been evaluated. Notably, surface anatomy approaches including body painting[45] and self-examination[75] have been shown to be effective when studying the musculoskeletal system. Evidently, there are limitations in the use of surface approaches for the study of musculoskeletal anatomy, with cadaveric dissection or prosection typically being the core learning resources used.[72,76] Furthermore, surface approaches are likely to restrict learners to the investigation of those superficial anatomical features that can be visually or haptically explored using living anatomy. However, this is not necessarily a major disadvantage of surface anatomy per se, as no anatomy learning activity, including dissection,[77] is recommended for use in isolation. The holistic and clinically relevant understanding of anatomy requires the discipline to be approached from a variety of perspectives,[25,78,79] and to be supported by supplementary content, with the integration of clinical imaging into gross anatomy teaching being a notable example.[80] To gain an appreciation of the spatial arrangement of deeper structures when not directly observing them, learners must access their knowledge of three-dimensional anatomy from prior experience, or from simultaneous usage of supplementary three-dimensional resources.[21,25,26] Furthermore, there is a considerable body of work underpinning the value of surface anatomy education as a discipline,[62,81,82] and additional support for the use of living anatomy approaches for studying the musculoskeletal system.[83-85] Indeed, surface approaches can enable learners to acquire considerable information regarding the structural arrangements of major bones, tendons, ligaments, neurovasculature, and the functional anatomy of joint articulations, gait, and locomotion.[75]

Haptic surface painting

Although there has been increased recent focus on active, experiential learning activities to improve understanding of anatomy,[86-88] there has been limited development of approaches to support visuospatial and metacognitive skills in anatomy learning and assessments.[8,28,89] Here, this area is addressed through presenting a description and evaluation of a novel Haptic Surface Painting (HSP) approach. The aim of HSP was to enhance learner anatomical spatial awareness (Table 1). When engaging in HSP, learners use their own living anatomy, or that of a fellow learner, to visually and haptically observe all palpable structures, completely and exclusively, in a particular anatomical region or system. Design of the HSP process has drawn upon key concepts derived from work describing both classical body painting[29,90] and the haptico-visual observation and drawing (HVOD) method[17,18] (Table 2). Furthermore, previous research has identified that combined visual and tactile observation can facilitate anatomy learning[17,25,32,37,91] through the formation of visual memories.[92] Moreover, learners and educators have reported that the subsequent retrieval of knowledge gained using haptic and visual observation may be achieved through visualization (Table 1) of cognitive representations created during the learning process.[17,18] Additionally, a growing body of literature has reported knowledge gains and positive student perceptions when drawing is used as an anatomy learning approach.[6,7,14,15,17,18,93] Painting and drawing of observable material are similar activities, which both involve the application of medium onto a surface and are, therefore, likely to involve similar cognitive processes,[94,95] which permits extrapolation of research findings from investigations of drawing approaches to the study of related art-based learning methods.

While there are clear similarities between HSP and classical body painting, there are also important distinctions between the aims, processes, and outcomes of these approaches (Table 2). For example, when HSP is performed on the anterior thoracic wall, the palpable elements of the pectoral and intercostal muscles, and the sternum, clavicle, ribs, and costal cartilage are all visually and haptically observed, and then painted with overlapping boundaries representing the layers of the body wall. In contrast, when classical body painting is performed on this region, the surface reflections of the heart and lungs would be painted based on inferences made from the identification of specific surface landmarks through palpation.[38,90] In doing so, the body painting process supports learners in clinical cardiovascular and respiratory examinations, which require auscultation of the heart valves and the lobes of the lungs. These differences in application reflect the contrasting purposes of classical body painting and HSP (Table 2). Evidently, major similarities between HSP and classical body painting concern the use of palpation, for landmark mapping in classical body painting and for observation in HSP; the application of colored media to the skin; and collaborative learning in pairs or groups. Additionally, neither learning activity is intended to be conducted in isolation, with both classical body painting and HSP being used to complement and reinforce cadaveric anatomy and clinical skills training when integrated within curricula.

TABLE 2 Comparison of the key features of classical body painting, haptic surface painting, and haptico-visual observation and drawing.

	Classical body painting	Haptic surface painting	Haptico-visual observation and drawing
Aims	Identification of two-dimensional surface landmarks, surface reflections and dermatomes to support clinical examination. Public and learner engagement	Exploration and discovery of the size, shape, positions, and relationships of the musculoskeletal system and neurovasculature to support development of anatomical spatial awareness	Exploration and discovery of isolated visceral and osteological specimens to support understanding of the three-dimensional form of anatomical parts
Observation	Prescriptive identification of predefined surface landmarks by palpation	Purposive visual and haptic observation of anatomical features that can be identified by palpation	Purposive visual and haptic observation of anatomical features that can be identified by palpation
Materials	Living anatomy of a partner or volunteer model. Opaque, translucent, or ultraviolet body paint medium	Living anatomy of the learner or that of a partner or volunteer model. Transparent food coloring medium	Household objects, anatomical models, cadaveric specimens. Paper, pencils, graphite, charcoal
Output	Single-layered, two-dimensional paintings of surface reflections on the skin of internal anatomical features inferred from positions of palpated surface landmarks and lines	Multi-layered and overlapping paintings on the skin to represent three-dimensional anatomical features identified by visual observation and palpation	Cross-contour drawings on paper to represent three-dimensional anatomical features identified by visual observation and palpation

Theoretical perspectives and conceptual framework

Constructivist learning theories have informed the design of HSP and can support the proposed value of the process. Constructivism comprises learner-centered educational theories that attempt to explain how learning is constructed and how understanding is retained,[96] through building upon prior knowledge.[97] Constructivist theories are therefore, analogous to the formation of memories in the brain through the modification and formation of networks from existing neurons.[98] Such a framework can describe how HSP may enhance learner spatial awareness, defined as a cognitive ability constructed from the experience of studying three-dimensional objects and concepts.[99-101] Furthermore, Kolb's experiential learning theory describes a cyclical constructivist model in which a learner first engages in a concrete experience and then reflects upon and analyzes the experience to construct new knowledge.[102] This model has been utilized to underpin prior art-based learning activities[6,89] including HVOD,[18] and provides a framework for repeated HSP cycles of haptic and visual observation, analysis through painting, and proposed gains in spatial awareness. Finally, the effective collaborative learning environment of HVOD[18] has been reproduced for in-person and remote delivery of HSP and has been informed by social cognitive learning theories.[103,104]

STUDY GOALS

Aims

This study aimed to provide a protocol for remote delivery of HSP learning activities and to deeply explore medical student perspectives of the theoretical, cognitive, practical, and logistical elements of HSP, in order to identify the value of the approach and to optimize design and delivery.

Research questions

1. How do medical students describe their experiences of HSP?
2. How do medical students describe the impact of HSP on their learning?
3. How do medical students perceive the mode of delivery of HSP?
4. How do medical students perceive that HSP may be applied to their anatomy curriculum?

To address these questions, research was approached from an interpretivist epistemological stance[105] using a broadly phenomenological methodology,[106] where learner perspectives of haptic surface painting was the phenomenon under investigation. It was hypothesized that, having practiced and experienced HSP, medical students would perceive that the activity influenced both their understanding of anatomy and their approaches to anatomy learning. Based on previous work by the authors describing the process and educator perspectives of HVOD,[18] it was expected that participants would report impacts on spatial and social learning and would recommend modifications for curricular implementation.

MATERIALS AND METHODS

Educational context

The first two years of the post-2017 medical program at Newcastle University (NU), United Kingdom, comprise the Essentials of Medical Practice (EOMP) phase of the curriculum. This phase is campus-based and is delivered in integrated case-led format, with teaching delivered throughout 25 consecutive clinical cases for year 1 ($n = 334$, 2020/21) and year 2 ($n = 330$, 2020/21) students. Anatomy teaching is delivered in blended format of preparatory self-directed tutorials delivered via a virtual learning environment, in-person whole cohort lectures, and in-person small-group practical classes in the anatomy laboratory. A combination of prosected anatomy specimens and technology-enhanced learning tools are the primary learning resources used by students. Teaching is delivered by anatomical region, as relevant to each case. Cardiovascular, respiratory, and gastrointestinal anatomy are integrated within Year 1 cases, while neuroanatomy and anatomy of the pelvis and limbs are delivered in Year 2. Further details of the educational context, learning environment, and curriculum of the preclinical EOMP phase of undergraduate anatomy education within the medical program at NU have been described in detail in previous work by the authors.[6,25,47] There is no formal anatomy teaching in Years 3–5 of the program. This phase is based at clinical sites around the North of East of England and comprises Clinically Based Practice (Year 3), Complexity in Medical Practice (Year 4) and Transition to Medical Practitioner (Year 5). Years 3 and 4 include integrated clinical placements in specialist departments, student selected components, and longitudinal integrated placements, while Year 5 comprises assistantships in medicine, surgery, and primary care.

Population and sampling

Undergraduate students registered for the 5-year medical degree program at the Newcastle University School of Medicine in academic year 2020/21 ($n > 1500$), were invited to attend a virtual HSP workshop via social media and email correspondence. Students ($n = 21$) registered their initial interest in participating via completion of an online form and were subsequently provided with a consent form and detailed research information. The final population ($n = 7$) confirmed their participation in the research by returning completed consent forms within the specified deadline.

Haptic surface painting workshops

Undergraduate medical students ($n = 7$) at Newcastle University attended optional online HSP workshops led by author L.S. that were virtually delivered via the Zoom videoconferencing platform (Zoom Video Communications, San Jose, California, USA). The undergraduate academic year at NU runs from September to June. At the time of their participation in July 2021, students were, therefore, on summer vacation having completed their Year 2 ($n = 6$) and Year 4 ($n = 1$) studies during academic year 2021/22. Consequently, participants had experienced all curricular anatomy teaching delivered within the NU medical program. All participants ($n = 7$) were female. Two sessions, Workshop A ($n = 3$) and Workshop B ($n = 4$), were delivered by L.S. on the same day and in an identical format, to introduce the concept and rationale behind HSP, and to guide participants through practical HSP activities, which involved each participant painting onto their own skin. While HSP activities were delivered and conducted remotely in this study, previous workshops have been delivered in-person to classes at the University of Cape Town and have involved students working in pairs, with each student painting onto the skin of their partner.

Introduction

Study goals and broad learning objectives were outlined in writing within the participant information documents and were provided verbally before each remote workshop commenced. Participants were informed that the aim of HSP was to improve anatomical understanding and spatial awareness by engaging students in an interactive teaching session, and that the study aimed to understand the value of HSP in the learning and teaching of human anatomy. Immediately prior to each workshop, a 30-minute lecture was delivered by L.S. The aim of this presentation was to introduce HSP as an activity designed to support and develop the spatial awareness of participants. Instances where such three-dimensional understanding can be applied to anatomical concepts were also described, for example when using spatial awareness to identify features in cross-sectional anatomy and clinical imaging.[25,26] Participants were also introduced to the manual exploratory procedures of active touch and palpation, and their associated object properties of lateral motion (texture); pressure (hardness); static contact (temperature); unsupported holding (weight); enclosure (global shape, volume) and contour following (global shape, exact shape).[18,107] Furthermore, this session provided an opportunity for the educator to build trust with the participants and to acclimate them to an unfamiliar learning approach. The lecture also enabled communication of the concept of palpation and painting as instruments with which to produce accessible visual memories, rather than as tools to create works of art or replications of illustrations from textbooks or atlases (Reid et al., 2018).[18]

Materials

Participants were advised to wear short-sleeved or sleeveless clothing so that the entirety of their upper limbs could be accessed. Skin-compatible food colorings and water brushes were recommended for HSP as the optimal marking medium and means of application, respectively. Food colorings are water-based, non-toxic and are visible when applied to both light and dark skin tones (Figure 1A). Colorings are also transparent, which enables adjacent and overlying anatomical features to be represented, as each underlying layer of color is visible through subsequent layers (Figure 1B). On completion of the activity, food coloring can be easily removed from the skin using soap and water. Disposable aprons are recommended to protect clothing. In this study, L.S. used Moir's brand food color (Pioneer Foods, Atlantis, South Africa) containing the following colorants: Red (E122), Yellow (E104, E122), Green (E133), and Blue (E124, E122) (Figure 1C). Water brushes purchased from Dala (Dala Art Materials, Western Cape, South Africa) with acrylic non-organic plastic fiber bristles, were used by L.S. (Figure 1D). Undiluted food coloring medium was contained

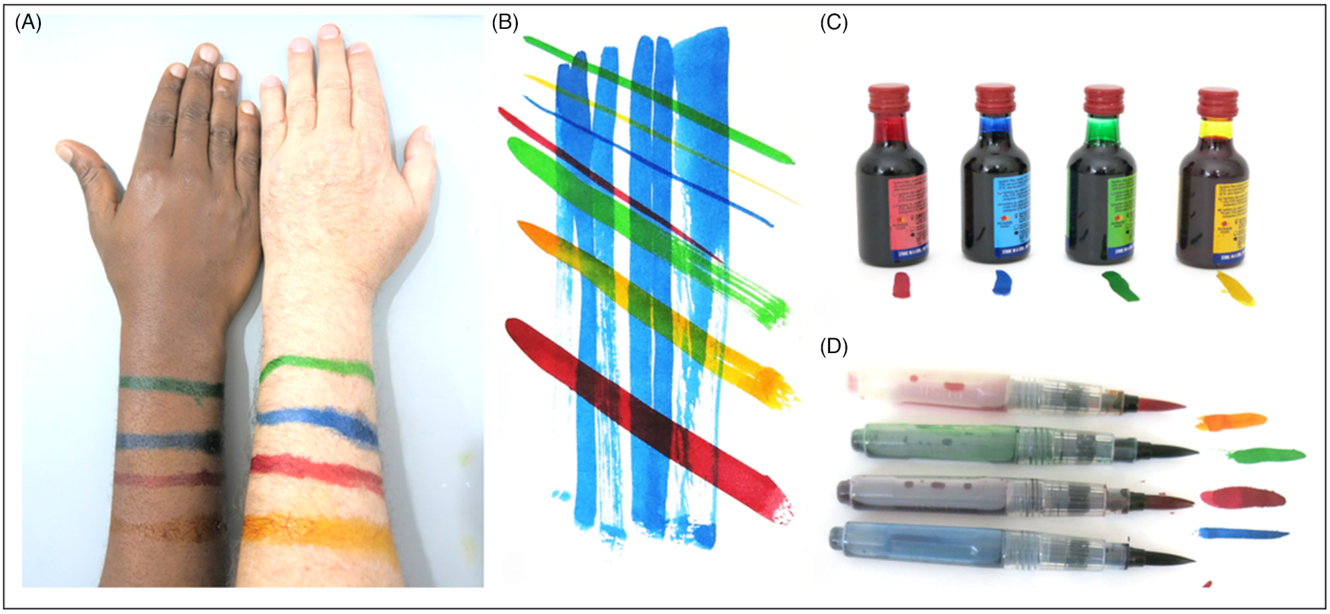

FIGURE 1 Haptic surface painting materials. Transparent colored medium is visible when applied to dark and light skin tones (A) and can be applied in an overlapping layered arrangement (B). Food colorings (C) can be applied using water brushes (D).

within the detachable reservoir of the water brush, which prevented spillage and simplified color application. Disposable 10 mL aspiration pipettes were used to transfer colors to the water brush reservoirs. Salex surfactant (Reitzer Healthcare, Johannesburg, South Africa) was used by L.S. to prevent beading of colors on the skin. Surfactant was mixed with coloring in each water brush reservoir (0.1 mL surfactant per 4.5 mL coloring). Water brushes were stored separately in plastic food containers for repeated usage.

Participants procured their own colorings, brushes, and surfactant from suppliers in the U.K. and were advised that if they were unable to access water brushes, then suitable alternatives could be used. Water brushes allow a controlled flow of liquid, whereas a normal paintbrush that is charged with food color is less controlled. Conventional organic fiber artist paint brushes can, therefore, be used for painting large musculoskeletal structures, while a cotton bud (Q-tip) can serve as a disposable applicator for painting the tendons and neurovasculature. When using these replacement tools, 4.5 mL coloring and 0.1 mL surfactant were gently mixed in a suitable glass or ceramic vessel. Dish washing liquid was recommended as an alternative and accessible surfactant for use by participants. All materials used by L.S. and participants were inexpensive, durable, and could be easily stored and transported for both remote and on-campus usage. At the time of purchase, material costs were equivalent to $US0.60 per 40 mL food coloring, $US2.70 per water brush, $US2.70 per artist paint brush, and $US1.00 per pipette.

Preparation

Immediately following the introductory lecture, participants were guided by L.S. to perform a preparatory upper limb activity, which corresponded to those described in Stage 1 of HVOD (Shapiro et al., 2020).[18] In this activity, participants were encouraged to move freely with their brush to make varied strokes on paper. They were also asked to note how, when transparent colors crossed, deeper layers of color remained visible beneath the superficial layers (Figure 1B). The aim of this activity was to introduce participants to the process of applying colors to the skin of their upper limbs. Participants became accustomed to using their brushes and colors, familiarized themselves with the purposive hand movements required to produce cross-contoured marks, and observed that colors could be overlapped to represent the arrangement of related anatomical structures. The process of purposive cross-contour drawing has been previously described by the authors.[18]

Palpation

When comfortable using the brushes and colors, the next preparatory step required participants to closely visually observe and simultaneously haptically palpate their own upper limb, in an analogous process to Stage 2 of HVOD.[18] Participants used haptic observation alone by globally palpating all identifiable superficial and underlying features of their own upper limbs, using their opposing hand and with their eyes closed. This process was intermittently combined with visual observation, discussions regarding the anatomical features being palpated, and prompting from L.S. to encourage further exploration. Participants were advised to avoid simultaneous use of any additional upper limb anatomy resources or lists of identifiable structures, as the aim of this activity was to support their haptico-visual exploration and formulation of a mental three-dimensional model of their own upper limb. It was intended that the activity would focus on the observation and visualization of the size, shape, and position of three-dimensional spatial topography, rather than on the structural and functional anatomy of named structures. While subsequently painting, it was intended that participants would recall and modify their visualized models.

Painting

Participants haptically and visually identified palpable structures of the upper limb, and then immediately apply paint marks to delineate the observed structures. Participants were asked to flex, extend, rotate, supinate, and pronate at the joints of their upper limb while concurrently observing, palpating, and painting features they had visually and haptically identified (Figure 2). A transparent color is applied to represent each feature observed, with painting proceeding in a deep to superficial direction so that deeper paint strokes are visible beneath an overlying color. The colors used were the choice of each participant and there was no specified color code associated with specific anatomical features. However, once a specific color was selected for describing each individual feature or type of structure, the same color was used consistently throughout the exercise. Any color that intersected with any other color, therefore, appeared as a mixture of the two colors at the intersection and, therefore, demonstrated distinct anatomical layers (Figure 2). For example, when the anterior aspect of the forearm was observed, various anatomical structures were palpated. Once identified, the radius and ulna were marked with, for example, yellow coloring on the skin. Subsequently, the wrist flexors and their tendons were marked in a distinct color (e.g., red) over the yellow-colored bones. Consequently, the areas of musculature that directly covered the bones would appear with orange coloration in this example, which emphasized the depth of

FIGURE 2 Example of haptic surface painting showing muscles and tendons (red), and bony landmarks (blue/green), in anterior (A, C), lateral (B), and posterior (D) views of the forearm and hand.

the observed anatomical layers. Participants were then encouraged to paint the palpable neurovascular structures of the forearm using a further color, for example, blue, or green.

While participants had access to only four colors, this did not limit their experience, as structurally distinct features could be delineated with the same color. For example, if bones and nerves were both painted yellow, considerable differences in the shape and arrangement of these structures would enable clear differentiation once painted on the skin. However, when considering the flexors and the radial and ulnar arteries at the wrist for example, it was important to denote the tendons and blood vessels in separate colors due to the comparable size, shape, and location of these structures.

Group discussion

While in-person communication and palpating and painting onto the skin of other participants or volunteers were not possible in this remote environment, it was important to encourage learner engagement in collaborative discussion.[18] During the HSP process, and again once paintings were complete, participants were encouraged to share and discuss their work on screen with each other and the facilitator. Because participants were working within the virtual Zoom environment, they were able to observe on screen the palpation and painting activities being conducted by their fellow participants. At appropriate points, L.S. utilized the Zoom "spotlight" function to enable a participant to show their paintings to the group. The preparation, palpation, painting, and group discussion stages of the workshop were conducted for a combined total of approximately one hour in duration.

Phenomenological study of learner perceptions

Based on the established principles of focus group design (Greenbaum, 1998; Stewart and Shamdasani, 2014)[108,109], a remote postworkshop focus group approach was developed and implemented. Workshop A attendees participated in semi-structured Focus Group 1 (FG1; $n = 3$; participant A, Year 4; participants B and C, Year 2) and Workshop B attendees participated in semi-structured Focus Group 2 (FG2; $n = 4$; participants D-G, Year 2), which both aimed to explore student views of HSP. Focus groups were held via Zoom (Zoom Video Communications, San Jose, California, USA) immediately following each workshop. In both FG1 and FG2, participants were encouraged by a facilitator (E.H.) to engage in discussion by describing their experiences of the workshop and the HSP process.

Participants were prompted by broad and open questions posed by E.H., which were based on the research questions outlined above. This was to ensure that perceptions arose spontaneously and extemporaneously from discussions, rather than being predetermined or influenced by the researchers. Example questions included: "How would you describe your experience of the workshop?"; "How you would describe the workshop to someone who has not previously experienced it?"; "What were you thinking about when you were going through the workshop activities?"; "What, if any, impacts did the workshop have on your understanding of how you learn?"; What, if anything, would you change about the workshop. Additionally, the following are prompts were used to check, clarify, and more deeply explore participant comments when necessary (where A,B, X, Y and Z denote specific points or general topics arising from the discussion): "Leading on from A, what are the thoughts of the group about B?"; "When you [individual participant] said the experience was X, in what way would you [the same individual] say it was X?"; "You [individual participant] mentioned Y earlier. Please could you [the same individual] explain further what you meant regarding Y?"; "We [the group] touched on Z earlier, please can you [the group] now go into a bit more depth about how you felt about the experience of Z?"; "Does anyone have anything more to add about A, B, X, Y, or Z?"

Text transcripts were automatically generated from Zoom recordings (Zoom Video Communications, San Jose, California, USA). Data cleaning of text transcripts was conducted manually while simultaneously reviewing audio recordings to ensure optimal accuracy of the text prior to analysis. Cleaned transcripts from FG1 (3255 words) and FG2 (4806 words) were analyzed in parallel using inductive semantic thematic analysis and independent and collaborative double-coding (E.H. and I.K.) to strengthen methodological rigor (Onwuegbuzie et al., 2009; Stewart and Shamdasani, 2014).[109,110] Analysis was conducted manually by highlighting codes and themes in transcript text documents. Author data analysis experience is provided here in accordance with published recommendations.[111] I.K. is a senior lecturer in anatomy with >20 years of research experience and >10 years of experience in anatomy education and pedagogic research. I.K. has extensive experience of qualitative data analysis, including performing analyses for the authors' previously published work.[18,25] E.H contributed to the work as an undergraduate project student and was trained in qualitative data analysis methods during the project.

Ethical assessment

The Newcastle University Faculty of Medical Sciences Ethics Committee granted approval for research (1844/18438/2019) in January 2019. The Newcastle University School of Medical Education Research Management Group approved this study in June 2021. Data collection commenced only when approvals had been granted. Participants gave informed written consent to participate in research. Participant data was stored confidentially and securely.

RESULTS

Four themes were constructed from thematic analysis of focus group transcripts. The authors have not made judgments on the relative importance of each theme. Such an approach to data interpretation would not have reflected the aim of this study, and transcript analysis did not reveal any theme to be perceived as being of greater or lesser value by participants. The four themes identified should, therefore, all be considered subjectively as important, related, but distinct elements of HSP.

Theme 1: Three-dimensional haptico-visual exploration

This theme was identified from participant comments describing the exploration of their own anatomy, and the visualization of anatomical structures gained from their visual and haptic investigations. Participants noted the importance of three-dimensional understanding, visualization, and interactivity in anatomy learning; that their understanding of three-dimensional anatomy had been focused, supported, or enhanced through engaging in three-dimensional haptico-visual exploration; and felt that this knowledge could be recalled and applied in future practical situations.

> [It is useful to] touch and feel to understand anatomy [in a] three-dimensional way. Especially because we don't always look at ourselves and be like ‘right, I can use what I have here to help teach myself anatomy.’ [It is a] useful way to think about what resources you have in your own body. [Participant F, FG2, Year 2]

> I definitely went and thought more about each bit I had painted and why I had painted it, what I could feel underneath. [Participant C, FG1, Year 2]

> I think it was a lot more about what you can [palpate] rather than what you [already] know is there. [Participant B, FG1, Year 2]

> I could spend so much time drawing out anatomy and I think this was a really efficient [approach], a quick way to go over all the surface anatomy…visually as well. I do have a feel of things when I am learning…but also the colors and everything…just kind of reiterated it for me. [Participant G, FG2, Year 2]

> I think it's a new fun way to learn, it's great for people who prefer visual and…more 3D and interactive way of learning. It's…just a great way to visually see the structures and understand a bit more. [Participant E, FG2, Year 2]

> I guess it's about thinking about how we can visualize structures under the skin. It's another way of visualizing the 3D-ness of anatomy and visually representing that. It's so useful being able to visualize things on yourself…in an exam or clinical situation, your arm is there…that's helpful because you can just visualize it and think about it in that situation. [Participant A, FG1, Year 4]

Theme 2: Cognitive freedom and accessibility

This theme was determined from participant comments noting that the HSP workshop provided an alternative experience to typical curricular anatomy classes. Participants appreciated being empowered with the freedom to explore anatomy without the cognitive burden of addressing the terminology and functionality of the anatomical structures under investigation, and valued liberation from the constraints of accuracy and appearance of paintings. In recognizing these elements, participants noted the importance of the HSP process itself for anatomical understanding, as opposed to the perceived quality of the paintings produced. Furthermore, enhanced accessibility to anatomy learning provided by the engaging nature of HSP was noted by participants who reported experiencing educational challenges when studying anatomy.

> I was having to use very different parts of my brain to what I would normally be doing in the [anatomy laboratory], and when we were doing the painting, I was quite enjoying that…it wasn't really right or wrong either, I was just thinking about it for myself and trying to work it out [Participant A, FG1, Year 4].

> I think to do this, you have to stop thinking ‘this muscle should be here, this muscle should be that’, and just feel. Which is quite nice to not be stressing about trying to name something and just feeling and trying to understand what's under there. [Participant C, FG1, Year 2]

> I think the small workshop is quite nice because it allows you to interact with students and have a bit more of a discussion but also it kind of leaves you to your own devices so it's very informal…you don't have to do it how everyone else is doing, [and] without the pressure of it looking nice. [Participant E, FG2, Year 2]

> It doesn't matter what it looks like, it's to help yourself. Sometimes [when studying] we'll do pictures and stuff like that, and it doesn't have to look good as long as it helps you. I think [HSP] fits into that category, it doesn't have to look good, doesn't have to make sense to anyone else, but if it makes sense to you and it's helpful whilst you are doing it. [Participant F, FG2, Year 2]

> As someone who's completely like not arty in any way, shape, or form and is terrible at painting, it was quite nice and relaxed and [L.S.] wasn't judging your

> painting ability. It was very much kind of 'do how you want to do it', which was nice. Pictures are optional… so it's not like anyone is saying 'You didn't paint that right'. [Participant G, FG2, Year 2]

> I can find [anatomy] quite tedious and quite difficult, so doing stuff like this makes you appreciate it a bit more and shows you that it can be fun. It's not always lots of names you have to learn, and things like that. So, I think [HSP] would be quite useful because it sort of engages you with [anatomy]. [Participant C, FG1, Year 2]

> I don't like anatomy and I just really liked this like as a different way of doing it. I don't like the [anatomy laboratory], I don't like textbooks, I don't like lectures, so I'm always open to finding new ways to learn anatomy. [Participant G, FG2, Year 2]

Theme 3: Altered perspectives of anatomy

This theme was determined from comments describing how engaging in HSP had encouraged participants to think differently about anatomy and their anatomy learning. Participants reported developing their depth of understanding and recall of anatomical structures and relationships when using this alternative learning process, which was identified as providing a contrasting experience to the activities and resources they would typically engage with during curricular anatomy classes or clinical scenarios.

> When you're pushed to…find things to paint, that was what makes you really explore the anatomy rather than at just [a] basic surface level. [Participant A, FG1, Year 4]

> It's a simple introduction to approaching anatomy in a way that you might not necessarily [have] thought. I had previously thought on my arm, if I was to feel the surface anatomy that [there would] be mainly muscle and a bit of bone, but I started realizing that there's other ligaments or tendons, that they're quite prominent [in] my own arm, and…I was surprised at how much surface anatomy there was other than muscle. [Participant D, FG2, Year 2]

> [When using prosected specimens] we don't know where different things are in the body and what's the relationship, because we see it already laid out for us in a certain way. So, I think [HSP] would be quite good, as almost a surgery workshop…on a living body, 'what's this muscle's relationship to this bone?' sort of thing. [Participant D, FG2, Year 2]

> Doing something a bit different makes you remember certain things, even if it is just remembering some surface anatomy. It works so well with the musculoskeletal [anatomy] as well because you can see everything, you can feel everything…the muscles, bones. This is quite a different and quite a useful way to go. [Participant F, FG2, Year 2]

> I think it was actually really useful as you don't think much about your basic anatomy after first and second year, you think about clinically relevant stuff instead so it's actually really good. I've barely done any upper limb all year, so it was good to have that refresher and come back to it…like when I was palpating…I was thinking [about] how does this correlate with my [clinical] upper limb examination and my hand examinations. [Participant A, FG1, Year 4]

Theme 4: Delivery and context

This theme was constructed from participant comments describing their perceptions of when and how HSP could be utilized within formal curricular teaching. Reponses ranged between recommendations for delivery of HSP as a preparatory, integrated, or consolidatory approach, and there was agreement that HSP would be most effectively delivered as a small-group activity with educator guidance. Consistent with Theme 2, one participant noted that the workshop context was likely to be important in supporting cognitive freedom.

> If this was a study skills session towards the beginning of the year, and they taught you the basics of what you could be doing or how you could do it, it's very easy to do at home. Doing this alongside an anatomy session would be great, and I think especially with COVID-19 where we're not in the [anatomy laboratory] as much this would be really good as an applied anatomy session. [Participant F, FG2, Year 2]

> Applying learning in a bit more context would have definitely made it…more useful to help us with our anatomy, and I think as well to maybe mark on [the surface] and then just observe the movements, and how the surface anatomy changes with movements. If you were to do this workshop with anatomy teaching on one side, [it would be] a great way to explain how [surface anatomy] changes with pronation. [Participant E, FG2, Year 2]

> I guess if you're a first year…doing this first isn't necessarily helpful because you do not really know what

you're [palpating]. You could be [palpating] so many different things and not have a clue what they are. So, I think it's helpful to actually know [some anatomy] before...more of a way of revision or like helping me to understand better and revise and consolidate it better. [Participant E, FG2, Year 2]

When you are in a [small] group, you can compare, and you can discuss. He [L.S.] was looking at our arms and saying, 'can you do this, can you do that?' I don't think it would necessarily be as useful if you just sat on your own [or] in a big group. [Participant C, FG1, Year 2]

I feel like if it was in person, I'd feel more pressure to do it nicer and tidier and make it more accurate. But at the same time, I think in person, you could get a bit more help from a demonstrator [who could] point out the different muscles and bones and stuff. [Participant G, FG2, Year 2]

DISCUSSION

The phenomenological study described here has investigated medical student experiences and perceptions of a novel art-based learning approach. The major finding of this study concerns the transformation of learner perspectives of the musculoskeletal anatomy of the upper limb, and more generally, transformation of participant views of their own anatomy learning. Learners have reported influences of HSP on their visualization of upper limb anatomy, achieved through visual and haptic discovery of palpable anatomical structures. The encouragement of learner-centered agency in the exploration of anatomy was also identified as a key element of the process and may serve to provide accessibility for learners who may find anatomy a challenging discipline to study. Furthermore, learners experienced metacognitive realizations when engaging in HSP, and understood how the activity had transformed or reconstructed their understanding of the musculoskeletal anatomy of the upper limb. While HSP may not be a substitute for cadaveric anatomy or technology-enhanced learning, participants recognized the value of HSP as a supplementary approach that can create positive transformations in medical student anatomy learning when integrated appropriately within curricula.

Transforming three-dimensional understanding through haptico-visual exploration

As a fundamentally visual and three-dimensional discipline, it is of crucial importance that three-dimensional visual observation is utilized as a primary modality for the delivery of anatomical education.[26,27,112] Furthermore, the value of visual, haptic, and haptico-visual art-based approaches to anatomy learning have been previously identified.[6,18,25] Learners have reported here (Participants A, E) that HSP can support three-dimensional understanding through exploration of the upper limb. Participants recognized the importance of haptic learning, both alone (Participant B, C) and in combination with visual observation (Participant G).

Having haptico-visually observed the features and structures of their own anatomy, Participant A reported being able to visualize the three-dimensional arrangement of the anatomy of their own upper limb. This is an important goal of the HSP process, and the comment of this participant may reflect development of their spatial awareness. Distinct elements of spatial awareness concern an understanding of the relative anatomical volumes and structural relationships when visualized from distinct viewpoints within the global volume of the human body.[26,99,101,113,114,115,116] Consequently, it is proposed here that spatial awareness developed during haptico-visual observation may support learner visualization of three-dimensional anatomy for application to other educational and practical contexts. An example of this could be when applying an understanding of three-dimensional viscera to the interpretation of cross-sectional anatomy, a situation in which spatial awareness can also be achieved through combined use of digital images and physical models.[25] As previously described,[18] this concept is supported by findings from neuroscientific research, which have identified influences of multimodal and multisensory,[117-120] and art-based approaches[94,121,122] on long-term memory formation. The learning of spatial relationships appears to require both perception (derivation of information about pattern and form) and imagery (cognitive reconstruction of the perception). The more complex the visual image, the more difficult the reconstruction and the greater the error rate.[123] Furthermore, processing visual images appears to be a function of the right cerebral hemisphere,[116] and requires considerable time relative to that needed for one or two-dimensional learning.[124] Therefore, in addition to supporting haptic observation, there is likely to be value in HSP that relates to the provision of sufficient time within an appropriate learning environment for reconstruction and validation of three-dimensional concepts.

Transforming anatomy learning through cognitive freedom and accessibility

A tacit and implicit impact of HSP on anatomy learning is likely to involve learner self-directed experiences of exploring and discovering anatomy, as opposed to the prescriptive approach of identifying surface landmarks in classical body painting.[32,38,90] Here, learners (Participants A, C) reported that their approach to anatomy learning had changed. This transformation related to how they were actively able to construct their own understanding of the spatial arrangement of upper limb musculoskeletal anatomy through palpation when freed from the constraints of accuracy and terminology. Additionally, learners (Participants E, F and G) reported that being explicitly liberated from the requirement to produce accurate and esthetically appealing outputs was a valuable element of the HSP process. Such freedom has been previously reported as a benefit in one of the first major investigations of body painting as an anatomy learning approach. This study was conducted at the University Medical Centre, Utrecht, Netherlands where an anatomical body painting course had been designed and introduced.[90] Participants reported that the process of painting anatomy was more valuable for their learning than the creation of an exquisitely rendered final product. Moreover, the presence of a professional body painter was perceived as reducing the self-reliance of learners and placing unnecessary emphasis on artistic practice rather than on the accurate positioning of anatomical features.[90] Instructor input of this nature has been additionally determined as a limitation in an investigation of an observational drawing approach within a practical anatomy setting.[6] These findings are further supported by a recent study of visual note-taking activities, in which learners identified that the development of effective learning strategies and the creation of a community of practice was instrumental to the value of the approach, rather than the perceived esthetic quality of the final product.[91]

Previous work has identified areas of anatomy that learners can find challenging to study, which primarily involve the application of concepts,[125] and topics involving three-dimensional visualization[126] such as clinical imaging and neuroanatomy,[25,127] and as identified here, anatomical terminology [Participant C]. Challenges for learners when attempting to understand the three-dimensional arrangement of anatomy[25,28,114,128] have also been determined. Approaches that have typically been utilized to deliver anatomy and imaging include lecture-based teaching, laboratory practical classes involving cadaveric dissection and prosection, and technology-enhanced learning employing digital representations.[85,129,130] Learners who find these standard methods to be challenging, such as those involved in this study (Participant C, G) may, therefore, benefit from engagement in HSP as a suitable alternative to standard methods, due to the process reducing cognitive demands related to spatial manipulation.

Transforming learner perspectives of musculoskeletal anatomy

Because musculoskeletal structures tend to be large and well-defined in cadaveric specimens and other physical and digital resources, this typically provides increased learner accessibility for effective observation and visualization. Consequently, the cognitive load placed on learners may also be reduced (Gross et al., 2017; Khalil et al., 2005; Sweller, 1988; Van Merriënboer and Sweller, 2010)[131-134], which may make the study of musculoskeletal anatomy less challenging than other systems and regions. Nonetheless, alongside ongoing rises in the prevalence of musculoskeletal disease, the importance of delivering clinical-relevant teaching of this system has been described (Day and Ahn, 2010).[135] Furthermore, active learning and metacognition have previously been determined to be key areas of anatomy learning (Kassab et al., 2015; Markant et al., 2016).[8,89,136,137] Findings here indicate that HSP can transform the approach of learners when studying the musculoskeletal system through active engagement in the HSP process. This study also demonstrates that HSP can provide a new perspective of anatomy that may not be achieved using standard methods (Participant D), and that the active HSP learning process can support a deeper, global appreciation of musculoskeletal anatomy over and above what learners have previously acquired (Participant A, D, F). From learner perspectives identified here, it appears that HSP can encourage learners to consider their own exploration, discovery, and learning of anatomy. In this case, the HSP activity has promoted metacognition with respect to the ability of learners to apply their anatomy knowledge to clinical scenarios (Participant A, D), which is a fundamentally important skill for medical students and practicing clinicians.[130,138] These insights also suggest that HSP can provide a link for the increasingly important integration of musculoskeletal anatomical sciences education with clinical skills,[67,69,139] in a similar fashion to classical body painting.[32,38,39,90]

Optimizing delivery and context of haptic surface painting

The development of spatial skills is important for student understanding of anatomical relationships, and it is, therefore, proposed that spatial awareness should be acquired and developed by novice students of anatomy during their first year of medical study. As previously described,[25] when students begin learning gross anatomy, it is important that fundamental concepts are understood before moving on to specific knowledge acquisition. The development and appreciation of spatial awareness may serve as a threshold concept[140-142] as it is required to transform learner understanding of their prior study of biology using two-dimensional textbook or web-based image resources into an appreciation of the three-dimensional arrangement of anatomy. Findings presented here suggest that having prior knowledge of anatomy (Participant E) is important for successful application of HSP, and conversely that HSP is beneficial supporting anatomy learning gains (Participant F). These apparently opposing ideas can be aligned based on constructivist principles of building upon prior knowledge,[97] and learning from repeated cycles of experience.[102] As such, learners gradually form an understanding of the three-dimensional nature, structure, and variations of the human body as they progress through the practical study of anatomy.[114] The optimal point for introducing HSP into curricula is likely to require the judgment of individual educators, based on the needs of their own learners. It is recommended, however, that HSP would be introduced at a relatively early stage of anatomy studies, once learners had achieved a grounding in the key gross anatomical structures, and in the basic principles, concepts, and terminology of the discipline. The HSP process is also recommended for delivery as a supplement to core anatomy teaching. As both cadaveric anatomy and HSP comprise tactile engagement with three-dimensional anatomical structures, there may be value in combining these complementary approaches. Such ‘hands-on’ activities are likely to provide students with training in skills such as spatial appreciation and orientation.[113]

Limitations

Limitations of haptic surface painting

Administrative and practical limitations of classical body painting have been previously described.[39] While detailed instruction guides may be necessary for learners to conduct classical body painting, this is likely to be of lesser importance for HSP, as the painting process is more flexible and less prescriptive. In HSP, painting is integral to the visual and haptic observation process, and secondary to an esthetic outcome. Gaining permission for photography is also less of a consideration for HSP due to the nature of the outputs produced. Nonetheless, certain limitations of classical body painting will also apply to HSP. Educators should consider and support the accessibility, dignity, and comfort of learners engaging in both remote and in-person HSP classes. Learners are likely to be required to give informed consent to participate in HSP, due to potential sensitivities associated with painting onto the skin. Participants may not be comfortable undressing around others and will need to remove paint from their skin, so classrooms with screens or curtains and nearby washing facilities are recommended.[39] Some learners may not wish to engage in HSP within group-based situations for cultural, religious, or other reasons. In such cases, these individuals can be allocated into pairs and will paint onto the skin of a partner who has volunteered to act as the “canvas”.[39] In remote learning scenarios, working in pairs may not be feasible, and palpating and painting oneself may be challenging, depending on the region being considered. These limitations can be mitigated by introducing HSP for exploration of the anatomy of the head and neck region, and of the upper and lower limbs during both remote and in-person group scenarios. Participants can wear appropriate clothing to allow access to these regions. Once familiar with HSP, learners may move on to thoracic, abdominal, and pelvic anatomy in further asynchronous self-directed activities. Remote delivery of HSP will require learners to acquire their own brushes and painting media, but as described above, purchase costs incurred are likely to be minimal.

Limitations of research

In this study, workshop and focus group participants engaged in optional activities during their summer vacation. Additionally, participants may have had a prior interest in art-based learning of anatomy. In turn, this may have influenced their engagement in the workshop and their perceptions of HSP. All participants ($n = 7$) were female, were learners at the same medical school, and most ($n = 6$) were from the same Year 2 cohort. Although member checking of focus group transcripts was not performed, checking of responses was conducted by the facilitator (E.H.) during the focus group discussions to ensure that any potentially ambiguous participant comments were clarified. Furthermore, the relatively small number of study participants may have resulted in saturation of perceptions not being achieved in this case. Future work may benefit from investigating a larger and more diverse population of learners, in both remote and in-person contexts, in order to identify the perceptions of male students and to increase transferability of the findings to different situations. For example, sex differences have been identified with respect to spatial ability,[28] and so males may have alternative views regarding this element of HSP. As conducted in previous work by the authors,[18] it would also be valuable to identify educator perspectives of HSP to identify broader views relating to pedagogy and curricula integration. Additionally, future studies may be conducted from a postpositivist epistemological perspective to triangulate the findings from this study. It will be particularly important to identify the intended impacts of HSP in terms of the development of learner spatial awareness and the application of this skill to the understanding of anatomy.

CONCLUSION

The description and evaluation of a novel art-based learning approach, which has been designed to support development of learner spatial awareness, has been presented. Findings indicate that HSP workshops can transform perspectives of the three-dimensional nature of the musculoskeletal system by providing learners the freedom to explore and discover living anatomy. Rather than being delivered as a standalone activity, it is recommended that HSP should be integrated with standard anatomy teaching as a supplement to cadaveric and technology-enhanced resources. This work will have implications for educators seeking to provide a flexible and engaging learning approach in musculoskeletal anatomy, which can achieve specific outcomes distinct from classical body painting. Future work can further investigate the value of this approach using experimental and survey-based studies and can explore the integration and remote delivery of HSP within an existing “Exploring 3D Anatomy” massive open online course, described previously by the authors.[18]

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