BMC Medical Education

RESEARCH

Open Access

Haptic experience to significantly motivate anatomy learning in medical students

Martha Manrique[1], Iván F. Mondragón[2], Leonardo Flórez‑Valencia[3], Luisa Montoya[4], Ananías García[5], Carmen Alicia Mera[5], Angelika Kuhlmann[5], Fabricio Guillén[5], Michelle Cortés[5] and María Lucía Gutiérrez Gómez[5,6*]

Abstract

Background Currently, multiple tools exist to teach and learn anatomy, but finding an adequate activity is challenging. However, it can be achieved through haptic experiences, where motivation is the means of a significant learning process. This study aimed to evaluate a haptic experience to determine if a tactile and painting with color marker interactive experience, established a better learning process in comparison to the traditional 2D workshop on printed paper with photographs.

Methods Plaster bone models of the scapulae, humerus and clavicle were elaborated from a computerized scan tomography. Second year undergraduate medical students were invited to participate, where subjects were randomly assigned to the traditional 2D method or the 3D plaster bone model. A third group decided not to join any workshop. Following, all three groups were evaluated on bone landmarks and view, laterality, muscle insertions and functions. 2D and 3D workshop students were asked their opinion in a focus group and answered a survey regarding the overall perception and learning experience. Evaluation grades are presented as mean ± standard deviation, and answers from the survey are presented as percentages.

Results The survey demonstrated the students in the 3D model graded the experience as outstanding, and in five out of the six questions, answers were very good or excellent. In contrast, for students participating in the 2D workshop the most common answers were fair or good. The exception was the answer regarding the quiz, where both groups considered it good, despite the average among all groups not being a passing grade.

Conclusions To learn the anatomy of the shoulder, the conventional methodology was compared with a haptic experience, where plaster bone models were used, enabling students to touch and paint on them. Based on the focus group and survey this study revealed the 3D workshop was an interactive experience where, the sense of touch and painting greatly contributed to their learning process. Even though this activity was useful in terms of learning bone landmarks, view muscle insertions, and establish relations, further activities must be developed to increase their understanding regarding their function, and its relevance in a clinical setting.

Keywords Significant learning, Integration, 3D bone models, Painting

*Correspondence:
María Lucía Gutiérrez Gómez
mlgutierrez@javeriana.edu.co
[1]Industrial Engineering Department, School of Engineering, Pontificia Universidad Javeriana Bogotá, Bogotá, Colombia
[2]Department of Industrial Engineering, School of Engineering, Pontificia Universidad Javeriana, Bogotá, Colombia
[3]Department of Systems Engineering, School of Engineering, Pontificia Universidad Javeriana, Bogotá, Colombia
[4]Department of Clinical Epidemiology and Biostatistics, School of Medicine, Pontificia Universidad Javeriana, Bogotá, Colombia
[5]Department of Morphological Sciences, School of Medicine, Pontificia Universidad Javeriana, Bogotá, Colombia
[6]Institute of Human Genetics, School of Medicine, Pontificia Universidad Javeriana, Bogotá, Colombia

Background

Teaching anatomy to medical students represents a constant challenge, due to the complex structure of the human body, its importance during the early stages of medical education, and its implications in future clinical practice, as it provides understanding of the structure and its function [1–4]. To obtain a clinical integration, the student must become proficient in anatomical structures and their respective function, which lead to acquiring medical terminology and prepares the future healthcare professional for determining diagnosis. In addition, it is especially advantageous in certain fields, such as surgery, where it has been described to offer patients greater safety [5, 6].

Although, to learn anatomy cadaver dissection is considered the gold standard [7, 8], high maintenance costs, exposure to toxic chemical substances, the lack of professors trained in anatomy dissection, curricular limitations and integrative curricula, among others, have led to the implementation of different methods and tools to teach anatomy such as, lecture sessions, laboratories, prosection, videos, interactive screens (such as Sectra and Anatomage), plastination and others [9, 10]. To date, no teaching tool meets all curriculum requirements; therefore, the best way to teach modern anatomy is by combining multiple pedagogical resources to complement each other [10]. Understanding 3D spatial anatomical relationships requires of the student to have a solid structure comprehension and 3D mental visualization skills [11]. It has been described by Rizzolo and Stewart, 2006 [12] and DeHoff et al. 2011 [13] that tactile manipulation, in addition to involving other senses, is a great advantage provided by cadaver dissection. Therefore, it might be associated with better understanding and retention of spatial information [11].

In this context, the haptic experience arises as an innovative tool, promising to increase the student's motivation, and facilitate a significant learning process. It seems to have a positive effect on long term memory with an impact on cognitive ability, especially at the level of the student's satisfaction [14, 15]. A haptic experience uses the sense of touch, associated with sight to explore and understand the form, texture, and the 3D characteristics of an object [16]. Moreover, physical manipulation allows active control of a model; hence, permitting visualization from multiple perspectives, and the capacity to establish relationships [17]. Collectively, 3D models have been demonstrated to be versatile and easy to manipulate.

Diverse modalities of haptic experiences have been evaluated, such as interactive 3D models and advanced haptic technologies, to determine their impact on anatomical knowledge acquisition and their capacity to develop a connection between theory and practice, both for undergraduate and post-graduate education [18, 19]. Applying this focus on teaching anatomy not only seeks to surpass the limitations in traditional methods, which are usually centered on passive memorization, but to stimulate active participation by the student in his or her autonomous learning process.

In post-graduate clinical training, various studies have used haptic cues with 3D prototypes to strengthen the understanding of anatomical and surgical procedures, as an aid in the clinical practice. Using 3D printed models helps to understand abstract concepts through spatial visualization and establish relationships. One such example is a study where a 3D printed liver with tumors model was utilized to understand surgical procedures and establish better cooperation at different training levels [20]. Another study used a physical model of an acetabular fraction to evaluate the effect of a tactile feedback, allowing the residents to feel resistance, contours, textures, and edges of fractures [21].

Acknowledging the importance of the haptic experience in the educational context, this research sought to provide several valuable insights to teachers, curriculum designers and healthcare professionals interested in optimizing human anatomy teaching, promoting a pedagogical approach that not only transmits information, but inspires a deep and long-term understanding of human anatomy. This study aimed to investigate the effectiveness of a haptic experience and painting on 3D plaster models as a motivating strategy to enhance meaningful learning of the shoulder's anatomy.

Methods

The following study evaluated a haptic experience to motivate meaningful learning in anatomy between March 2021 and March 2023. To this end, skeletal elements of the shoulder were modelled in plaster to determine if a tactile workshop and interaction with color markers would establish a better learning process, in comparison with the traditional method using a written 2D workshop. This study was carried out with undergraduate second year medical students from Pontificia Universidad Javeriana, Bogotá.

Plaster bone model

To elaborate realistic physical bone models from the human shoulder computed tomography (CT) images were obtained from volunteers after signing informed consent (FM-CIE-0113-18). Digital Imaging and Communication in Medicine (DICOM) files from CT scan were segmented with an on-house algorithm and converted into a CAD format, using an isocontour algorithm. Using a rapid prototype system, CAD files were used to 3D print a scapula, humerus and clavicle prototype in ABS plastic. Following, each prototype was employed to elaborate a silicone model into which plaster was poured into and allowed to set. The piece was released from the mold and the excess material was removed to have a replica of the skeletal element to be used in the 3D workshop with the students. At least 12 prototypes for each bone were created.

Study design

The study was approved by the Ethics committee of Pontificia Universidad Javeriana, Bogotá, School of Medicine project No. 8259 (FM-CIE-0113-18). To carry out this research, 85 second year undergraduate medical students were invited to take part in this study (62 female (73%) and 23 males (27%) between the ages of 19 and 25, where 77 participated in this study anonymously, representing 91% of the fourth semester class. Gender distribution was 71% females and 29% males. It was made clear it would not influence their grades, and they could withdraw from the study at any moment. Signed inform consent was obtained from all participants (Act No. FM-CIE-0010-23).

At the time of the study, subjects had completed two hours of lecture on the anatomy of the shoulder, without any practical component. Subjects were divided into random groups, assuming students held a similar anatomical knowledge. A first group answered the conventional workshop (n=24, females: 21, males: 3), herein referred to as 2D. A second group of 28 students participated in the 3D workshop (n=28, females: 21, males: 7) and a third group, referred to as control, decided not to participate in either of the workshops (n=25, females: 13, males: 12), but did participate in taking a 10-question quiz at the end of the study.

The same written workshop regarding the anatomy of the shoulder bones was distributed among the two groups (2D and 3D workshops). Students could organize themselves into subgroups with no more than four students per subgroup. The activity was first explained for both groups by one of the professors leading the study. Subjects were handed out a printed workshop with black and white photographs of the scapulae, clavicle and humerus and a table to fill in. Students had 90 min to provide answers regarding the name of the skeletal element, bone laterality, and the view of the bone based on the photograph. In addition, the workshop contained a table with the names of 18 shoulder muscles. Subjects had to determine bone marking, muscle origins and insertions, and function, according to a given color code. To this end, they could use anatomy atlases, and information from the internet (Fig. 1).

For the study, the 2D and 3D groups were divided into two different classrooms: The 2D group performed the workshop in a lecture classroom, whereas the 3D group carried out the activity in an anatomy laboratory, where each group worked on a table with scapulae, clavicle and humerus plaster models and color markers. For the 3D workshop, in addition to writing the answers on paper, bone markings (projections and depressions) and muscle insertions were painted on the plaster bone models using a color code.

At the end of the activity, all three groups, 2D, 3D and those not participating in either workshop (control group) had to answer a 10-question quiz under examination conditions related to anatomical markings, bone laterality, view of the bone, muscle insertion, and muscle function. They had a 20-minute time span to answer the quiz, without access to any of their learning material. The maximum score achievable was 5.0 and the minimum 0. After this activity, a focus group was performed with the two groups. A week later, a graded survey was conducted for the 2D workshop group, consisting of six questions addressing how the workshop contributed to their understanding of anatomical landmarks, muscle insertions, and articular movements. In addition, they were asked to grade the overall experience, how it contributed to their learning process and if the quiz questions were related to what they had learned in the activity. For the 3D workshop group, two additional questions were included: if bone manipulation and painting on bone plaster models

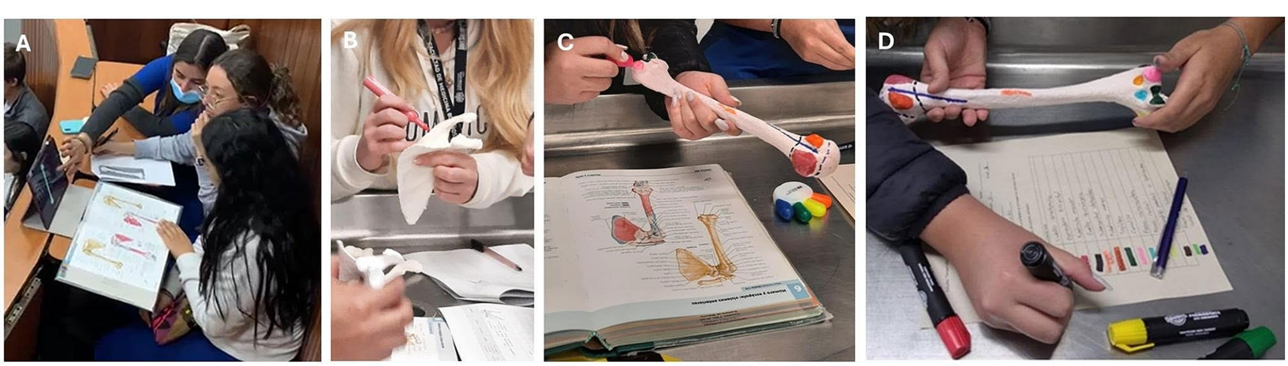

Fig. 1 2D and 3 D workshop groups. (**A**) Students carrying ou 2D workshop in the classroom. (**B**) Student in the 3D workshop painting over the structure with color marker. (**C**) Students in the 3D workshop using anatomy atlas and painting on the structure to identify bone landmarks. (**D**) Students in the 3D workshop filling in table in written workshop

had an added value in their learning process. Moreover, to gather feedback from all participants, two open questions regarding the two main strengths and weaknesses of this activity were answered by all students who participated.

Data analysis

This was a descriptive cross-sectional study. Data for quiz results are presented as mean ± standard deviation (SD). To determine normal distribution a Shapiro-Wilk test was performed, and an ANOVA test was carried out to establish significant differences among groups with a $p<0.05$. For survey, responses are presented as percentages from a six-degree Likert scale: 1: very poor, 2: poor, 3: fair, 4: good, 5: very good, 6: excellent, results are presented as percentages. Stata software (College Station, TX USA) version 17.0 was used to analyze all data. Graphs were made with GraphPad version 8.0 (Boston, MA USA).

Results

Survey results

Regarding the question on how the students perceived the workshop overall (Fig. 2), 3D students graded the workshop as very good (35.7%) and excellent (53.6%), whereas the 2D group graded it as fair (34.8%) and good (30.4%).

On how it contributed to the learning process (Fig. 3A), the 3D group rated it as good 21.4%, very good 42.8% and excellent 28.6%. On the contrary, the majority of the 2D group considered it fair (43.5%). Understanding anatomical landmarks (Fig. 3B) was graded by the 3D group as good (39.3%), and excellent (50.0%), compared with poor (27.3%), fair (27.3%) and good (40.9%) grades given by the 2D workshop students. For the question regarding muscle insertions (Fig. 3C), 63% of the students in the 3D group gave it an excellent mark. In contrast, for this question 8.7% of the students in the 2D group considered it was very poor. Last, understanding joint movement was graded by 3D workshop students for the most part as good (35.7%), whereas 52.2% of the 2D group considered it was poor (Fig. 3D).

Because of the nature of the study design, students in the 3D workshop group answered two additional questions: manipulating the bones and its impact on significant learning was graded as excellent (67.9%), and even though it received a high mark (excellent 64.3%), painting on the bones seemed to have a lower importance in their learning process (Fig. 4).

Focus group results

In addition, based on the focus group, the 3D workshop students commented it was helpful to see structures in 3D and establish associations, which is difficult when working with 2D images. Most found it was useful to understand bone laterality view and muscle origin and insertion. It asserted their knowledge, as it allowed to dimension how the bone is structured, reinforcing spatial location. In comparison to working with 2D images, such as an anatomy atlas or the lecture on the subject, the students referred it to be different when one touches the structure vs. reading about it. The 3D workshop promoted learning through collaborative work between students, complementing each other's knowledge. From the focus group, it was evident that the tactile models allowed for a three-dimensional appreciation of the

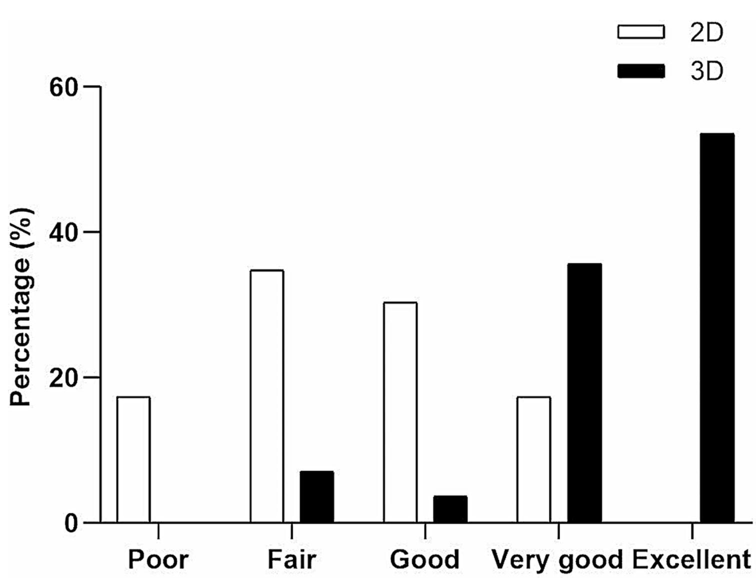

Fig. 2 Survey question regarding how 2D and 3D students perceived the workshop. Blank bars are the percentage of answers on a Likert scale for students participating in the conventional 2D workshop. Black bars are percentage of answers for the students participating with the 3D plaster bone models

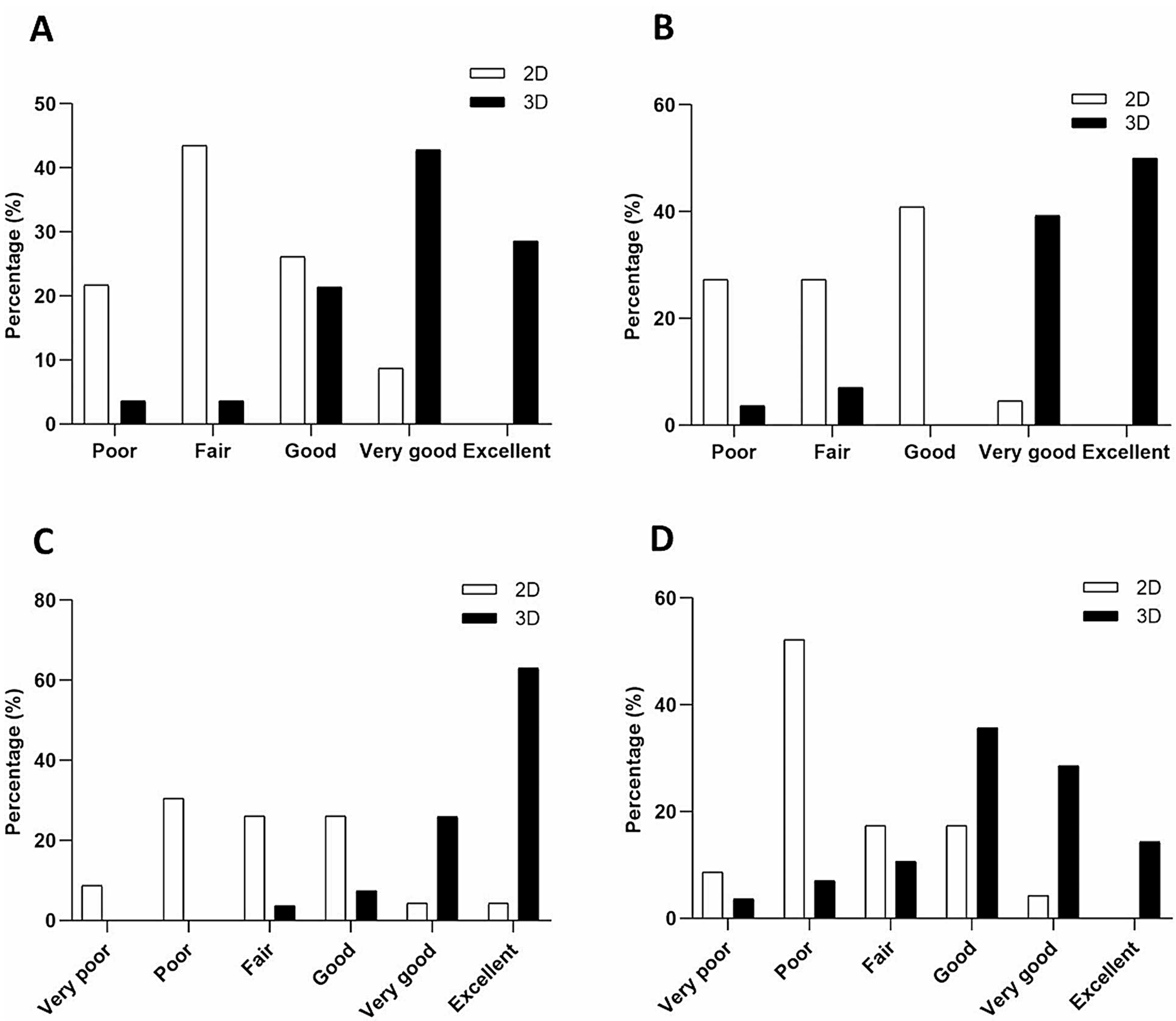

Fig. 3 Likert scale percentage of answers for 2D and 3D workshop. (**A**) Overall contribution on the learning process. (**B**) Understanding anatomical markings. (**C**) Understanding muscle insertions. (**D**) Understanding joint movement. 2D workshop: White bars, 3D workshop: Black bars

bones, their landmarks and respective muscle insertions, contributing to spatial metacognition. This result was not as strong for the 2D workshop.

In contrast, students in the 2D workshop said they had to rely more on the teacher's help. The process was more related to memorization rather than understanding. Printed photographs of the bone do not allow for good identification of bone markings.

For both workshops, an anatomy atlas was of great help. Moreover, bone articulation and clinical correlation was not sufficiently reinforced in this workshop, as evidenced by the results from the survey and the quiz.

Quiz results

Even though, students from the 3D group graded the workshop as very good or excellent in its majority, quiz results (Fig. 5) did not reveal a significant difference compared to 2D workshop performance or students who did not participate in any workshop (1.82 ± 0.88), 2D (2.05 ± 0.82) and 3D (2.09 ± 0.94). However, 21% of the 3D group had a passing grade, whereas only 16% from the 2D group and 8% from the control group had a passing grade. The highest grade (4.0 from a maximum of 5.0) were obtained by two subjects of the 3D group (7%). The best grade for the 2D group was 3.7 obtained by one person (4%). Last, for the control group the highest mark was and 3.5 from one student (4%).

Moreover, for the 3D group, five of the 10 questions had a greater percentage of students selecting the correct

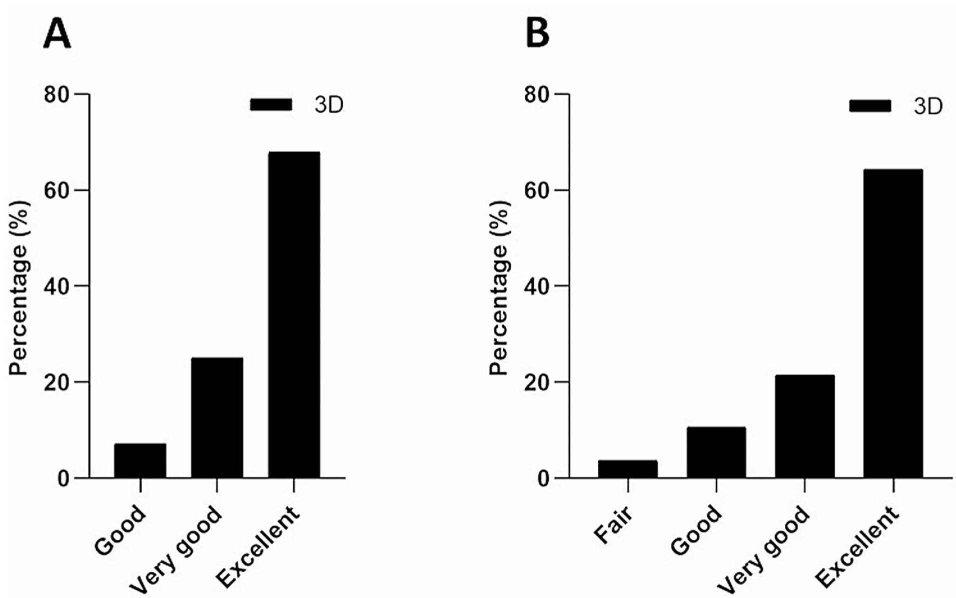

Fig. 4 3D plaster bone model impact on learning. (**A**) Bone manipulation, (**B**) Painting bone accidents and muscle insertions on bone structures

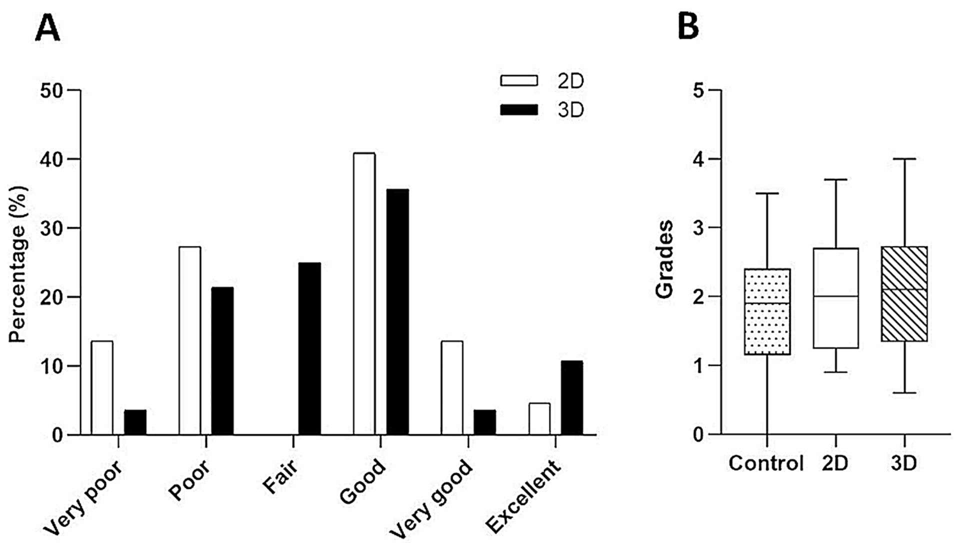

Fig. 5 Quiz grades. (**A**) Perception of students on the quiz. 2D workshop students: White bars. 3D workshop students: Black bars. (**B**) Grades on 10 question quiz regarding: Muscle insertion on bone accident, muscle function, clinical correltion, bone laterality, and joint movement. Control: Dotted box, 2D workshop students: White box. 3D worshop students: black hatched lines

answer. These included a question regarding the levator scapulae muscle insertion, to identify the view of the clavicle, an arrow pointing to a humerus landmark asking to identify the function of the muscle fibers inserting in the lesser crest of the humerus, an arrow pointing to the radial groove asking to identify the structure that associates to it. Last, an arrow pointing to the anatomical neck of the humerus, asking to identify the structure. For the 2D group, only one question had a greater percentage of students answering the right question (to identify the muscle inserting on the scapula bone landmark circled in red). Last, the control group had four questions for which a greater percentage of students answered correctly. The questions were related to the main function of the muscle inserting in the subscapular fossa, to identify the neck of the scapula, to identify the structure and function of the arrow pointing at the coronoid fossa, and to identify the crest of the lesser tubercle.

Discussion

This study aimed to develop new learning resources using bone plaster models to understand the shoulder's skeletal anatomy, focusing on bone landmarks and muscle insertions and origins. To this end, a customized, highly accurate plaster skeletal element from a 3D printed prototype was used to assess the efficacy as an anatomical teaching aid. To evaluate what students had learned, a quiz was applied to all subjects at the end of the activity. Additionally, to collect the views of the two approaches evaluated (conventional 2D vs. 3D), a focus group and survey were conducted to determine the subjects' educational benefits and perceptions.

At present, objective evaluation on comparative efficacies using conventional teaching resources and novel pedagogical tools, such as 3D prototypes remains scarce in the literature, since most studies are based on student perception, attitude and enjoyment [11]. The objective of the present study was to proof the hypothesis that students actively participating in the 3D workshop would obtain a significantly higher grade compared with 2D workshop or control subjects. However, results did not reveal significant differences (Fig. 5). As was observed from the 3D focus group, students described it would be more beneficial to have a lecture followed by a lab session to interiorize the information. Furthermore, subjects recounted this was the first time studying this subject; if they had a review session, they would have benefited more from the activity. In addition, they attributed the low performance on the fact that they had high-stakes examinations in the two weeks prior. In contrast, in studies where a post-test objectively evaluated the efficacy of a 3D model, test conditions were different: For the Preece et al. study [11], subjects had access to their teaching aids, and for Bao et al. study [20], a training took place three times a week, with each session lasting 40 min for four continuous weeks. Therefore, for both formerly mentioned studies, test scores were significantly higher for the subjects learning by a haptic experience. Last, in the Huang et al. study, the subjective questionnaire demonstrated the 3D experience was considered the most valuable and enjoyable learning instrument [21], suggesting this positive quality using 3D models can be employed towards developing educational resources.

In the present study, it was evidenced that a haptic experience involving painting on 3D plaster models of skeletal elements, aided in the learning process of the shoulder's anatomy by enhancing the student's anatomical spatial awareness. It is known that there has been limited development of activities that support visuospatial and metacognitive skills in anatomy [22, 23]. Therefore, with this innovative approach, the limitations that traditional methods, usually focused on a surface approach to learning such as memorization, might be overcome [24]. Preece et al. suggested that 3D physical models have a significant advantage over textbooks and virtual reality by improving visuospatial understanding. Furthermore, appreciating complex spatial relationships in 3D increases visual skills [11]. In their acetabular fracture study, Huang et al. described that by touching the anatomical landmarks and fracture lines in the 3D models, students could obtain spatial details of the morphology of the fracture that could not be acquired by the other methods evaluated. They concluded that 3D models are an efficient learning tool [21]. Hence, haptic cues may be crucial in learning about complicated structures.

In the present study, 3D group participants were able to identify bone landmarks by touching the structure. Students were made aware of bone landmark's that may not be otherwise noticeable in a 2D format (photograph, drawing or virtual image). The hand-held interactive experience allows for active control, permitting visualization from multiple perspectives. As concluded by Wainman et al., a physical model is superior to a computer projection, because of stereoscopic vision in the 3D structure [17]. In addition, the 3D model improves understanding, because the haptic experience develops the ability to integrate information, as described in the acetabular study: "form a complete chain from vision to touch, from plane to stereo, and from intact to fracture".

To achieve a deep learning approach, the student must understand the structure and manipulate the object to make sense of the relation between the elements. Hence, 3D plaster models of the shoulder skeleton were fabricated. Brumpt et al. carried out a systematic review describing the value of 3D printed anatomical models [14]. From their work, they selected 68 articles, of which 47 were designed from CT scans, and 51 articles mentioned bone printing. However, the shoulder was only mentioned in one study [25]. In the study of Garas and colleagues, 23 undergraduate students of health sciences were exposed to plastinated, 3D-printed models and cadaverous specimens of the external heart, shoulder, and thigh, where the shoulder was plastinated [25]. The students then had to take a test with nine questions on a pinned structure, and were asked to identify it. Afterwards, they were provided a post-test survey with five questions on a Likert scale. Collectively, from the Garas' study, it was concluded that 3D printing can be an asset in the process of learning anatomy [25]. Furthermore, the level of understanding was very basic and not comparable with the present study. Ye et al. carried out a systematic review and meta-analysis for the last decade [26]. They included studies using post-training tests, where 3D printed models of various systems, such as nervous system, and abdominal organs were used. Regarding student satisfaction, from their study it was observed that five of the six study results were significantly higher for the 3D group, in comparison with conventional groups. Likewise, concerning accuracy of answering questions, two studies showed the 3D group was significantly better in comparison with the conventional group. Collectively, subjective information obtained from survey can be as important as test scores.

In the present work, students from the 3D group described how important it was to touch, feel the texture, see the structure and establish proportions in the plaster bone models. The students expressed the added value provided by manipulating the three skeletal elements to establish associations and anatomical relations. Additionally, anatomical information was not fully understood from textbook reading or from explanations in a lecture. One student described how the main difficulty was establishing dimensions. The 3D spatial perception view allowed to understand proportions and locations. Additionally, painting on bone landmarks and muscle insertions made it easier to recognize their locations. Wainman et al. described how a haptic experience manipulating a 3D model, enhanced the learning process by providing additional sensory spatial relationships, which cannot be acquired by learning from 2D images; thus, enhancing the learning process [17].

To further this learning experience, painting was included in the 3D workshop, reinforcing the learning process. Other researchers have used 3D printing and painting to learn anatomy. McMenamin and collaborators reported on high resolution 3D prints of accurate color reproductions of prosections based on CT scan images [18]. Their article described in depth the process of creating the models, yet no evaluation with students was carried out.

In the present study, the overall experience was rated as very good or excellent by almost 90% of the 3D model group members. In contrast, 65% of the students in the 2D group rated the activity primarily as fair or good, and none of them rated it as excellent. Likewise, a study carried out by Pandya, Mistry and Owens [19], described the use of videoconferencing and use of tactile learning with 3D models to assess the differences in undergraduate students' attitudes toward tactile and non-tactile learning. In their results, students believed tactile learning was statistically superior ($p=0.017$).

Furthermore, Reid et al. described a study where five students participated in a special module entitled "Drawing and Anatomy" at the University of Cape Town [27]. Reid's study coupled exploring the skeletal element, such as a skull, with a haptic experience with one hand and drawing with the other hand. The students were then interviewed mid-way through their intervention. Collectively, the experience resulted in an increased comprehension of the 3D form and detail of anatomical landmarks and cavities. Likewise, herein we obtained similar answers from the 3D focus group. Other experiences using painting to learn anatomy were evaluated by Shapiro et al. [22]. In their study, they employed haptic surface painting to support learner engagement and spatial awareness. They described that hapticovisual observation can support spatial, holistic anatomy learning.

Haptic sensing involves perceiving a variety of object features, such as shape, size, weight, surface texture, compliance, and thermal characteristics [28]. In this manner, somatosensory haptic acquired information is also subjected to detailed analysis [29]. In our study, the students surveyed in the 3D model group perceived the haptic activity favored their overall learning process, rating it primarily between the very good and excellent, representing 71.5% of their answers; while in the group that used only 2D images, more than 60% perceived the contribution that the activity provided to their learning process as poor or fair.

The haptic experiences in this study support the argument that their implementation favors meaningful, autonomous and collaborative learning, characteristics that are sought in all academic activities in current medical education. The opportunity to work with the 3D plaster models and actively participate in painting on them, demonstrated a significant impact on the learning of the medical students who scored 90% in the very good and excellent categories. It is evident that the bone plaster models provided 3D metacognition of the structures, consolidating knowledge and making learning more motivating and satisfactory.

To achieve a comprehensive knowledge of bone markings, laterality, muscle insertions and joint movements, demands of the learner the correct spatial orientation of the structures involved. The group that worked with the 3D plaster bone models graded it in the survey as very good and excellent (between 85 and 90%). However, joint movement was not properly developed in this workshop. These same categories were rated between fair and poor (50–70%) for the 2D group. Collectively, haptic experiences in this study were shown to favor significant learning, characterized by an autonomous and collaborative approach.

Although results in this study were satisfactory, one of the limitations observed was the duration of the workshop, which only lasted 90 min. As with the Waiman et al. study, learning time was brief [17]. It could be expected that another 90-minute laboratory might allow students to recognize bone articulation and movements, rather than identifying a bone landmark without understanding its function. Even though, one of the learning objectives of this activity was to recognize different components of the shoulder in diagnostic images to establish associations between them, this was not achieved. Anatomical understanding must precede diagnostic images, as was the means of objectively evaluating the 3D tool in the Preece study [11]. Therefore, radiological images should also be included in the workshop, to verify if learned concepts can be applied in a clinical setting. Moreover, a pre-test should have been carried out to assess the level of anatomy knowledge of all participants. Last, evaluations of this nature should not be implemented after midterm examination, as they might affect students' performance.

Conclusion

A highly accurate 3D plaster model was custom made, so students could appreciate the bones' landmarks, identify muscle origins and insertions, and understand their function. Such tools contribute to the development of skills that allow students to face various future situations in clinical practice with greater proficiency and confidence. The results from our study demonstrated that a haptic experience increased motivation and satisfaction. Furthermore, painting on a particular bone landmark required from the student to combine the senses of touch and sight to establish spatial relationships; thus, reinforcing the learning process. Additionally, in the 3D workshop, students actively participated in their autonomous learning process. Furthermore, teamwork helped solve questions and complete tasks, while learning new concepts. Hence, new collaborative learning was stimulated, as evidenced from the 3D model focus group. However, this workshop must be complemented with activities that increase the understanding of muscle movement and bone articulation for better integration to clinical settings.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-05829-w.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Acknowledgements

Authors thank Dr Magda Alba for her valuable insights in performing this study.

Author contributions

M.M. and I.F.M.: conceived and designed the study. L.F-V.: conceived and designed the study. Created isocontour algorithm. LM. designed the study, analyzed and interpreted data, contributed in writing the manuscript. A.G., C.A.M., A.K., F.G.: conceived and designed the study. Carried out "2D and 3D workshops, contributed in writing the manuscript. M.C. conceived and designed the study, obtained financing to carry out this study.M.L.G.G. conceived and designed the study. Carried out "2D and 3D workshops, contributed in writing and revising the manuscript. All authors reviewed the manuscript.

Funding

This Project was financed by the Pontificia Universidad Javeriana Vice-rectory of Investigation (VRI) Project No. 8259 and No. 21155.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The authors were accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved. Both CT images were anonymized before use for 3D modeling and had signed informed consent (FM-CIE-0113-18). For the 2D and 3D workshop student participation was approved by the Ethics Committee of the Pontificia Universidad Javeriana School of Medicine (Act No. FM-CIE-0010-23). This study was conducted according to the standards of the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 16 April 2024 / Accepted: 29 July 2024
Published online: 30 August 2024

References

1. Older J. Anatomy: a must for teaching the next generation. Surgeon. 2004;2(2):79–90. https://doi.org/10.1016/S1479-666X(04)80050-7.
2. Turney BW. Anatomy in a modern medical curriculum. Ann R Coll Surg Engl. 2007;89(2):104–7. https://doi.org/10.1308/003588407X16824.
3. Cheung CC, Bridges SM, Tipoe GL. Why is anatomy difficult to learn? The implications for Undergraduate Medical Curricula. Anat Sci Educ. 2021;14(6):752–63. https://doi.org/10.1002/ase.2071.
4. Mwabaleke JA, Usman IM, Tito AE, Edet Obeten K, Umar Isyaku M, Etukudo EM, Fischer VA. Perceptions and challenges Faced by Undergraduate Medical students in studying anatomy: a case study at Kampala International University - Western campus, Uganda. Adv Med Educ Pract. 2023;14:1129–35. https://doi.org/10.2147/AMEP.S427136.
5. Aziz MA, McKenzie JC, Wilson JS, Cowie RJ, Ayeni SA, Dunn BK. The human cadaver in the age of biomedical informatics. Anat Rec. 2002;269(1):20–32. https://doi.org/10.1002/ar.10046.
6. Goodwin H. Litigation and surgical practice in the UK. Br J Surg. 2000;87(8):977–9. https://doi.org/10.1046/j.1365-2168.2000.01562.x.
7. Ghosh SK. Cadaveric dissection as an educational tool for anatomical sciences in the 21st century. Anat Sci Educ. 2017;10(3):286–99. https://doi.org/10.1002/ase.1649.
8. Estai M, Bunt S. Best teaching practices in anatomy education: a critical review. Ann Anat. 2016;208:151–7. https://doi.org/10.1016/j.aanat.2016.02.010.
9. Funjan K, Ashour L, Salameh M, Mustafa A, Seed Ahmed M. Perceptions and attitudes of Jordanian Medical students on using 3D interactive anatomy dissection in teaching and learning anatomy. Adv Med Educ Pract. 2023;14:837–44. https://doi.org/10.2147/AMEP.S419333.
10. Davis CR, Bates AS, Ellis H, Roberts AM. Human anatomy: let the students tell us how to teach. Anat Sci Educ. 2014;7(4):262–72. https://doi.org/10.1002/ase.1424.
11. Preece D, Williams SB, Lam R, Weller R. Let's get physical: advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. Anat Sci Educ. 2013;6(4):216–24. https://doi.org/10.1002/ase.1345.
12. Rizzolo LJ, Stewart WB. Should we continue teaching anatomy by dissection when …. Anat Rec B New Anat. 2006;289(6):215–8. https://doi.org/10.1002/ar.b.20117.
13. DeHoff ME, Clark KL, Meganathan K. Learning outcomes and student-perceived value of clay modeling and cat dissection in undergraduate human anatomy and physiology. Adv Physiol Educ. 2011;35(1):68–75. https://doi.org/10.1152/advan.00094.2010.
14. Brumpt E, Bertin E, Tatu L, Louvrier A. 3D printing as a pedagogical tool for teaching normal human anatomy: a systematic review. BMC Med Educ. 2023;23(1):783. https://doi.org/10.1186/s12909-023-04744-w.

15. Hutmacher F, Kuhbandner C. Long-term memory for Haptically explored objects: Fidelity, durability, incidental encoding, and cross-modal transfer. Psychol Sci. 2018;29(12):2031–8. https://doi.org/10.1177/095679761880364.
16. Klatzky RL, Lederman SJ. Haptic object perception: spatial dimensionality and relation to vision. Philos Trans R Soc Lond B Biol Sci. 2011;366(1581):3097–105. https://doi.org/10.1098/rstb.2011.0153.
17. Wainman B, Wolak L, Pukas G, Zheng E, Norman GR. The superiority of three-dimensional physical models to two-dimensional computer presentations in anatomy learning. Med Educ. 2018;52(11):1138–46. https://doi.org/10.1111/medu.13683.
18. McMenamin PG, Quayle MR, McHenry CR, Adams JW. The production of anatomical teaching resources using three-dimensional (3D) printing technology. Anat Sci Educ. 2014;7(6):479–86. https://doi.org/10.1002/ase.1475.
19. Pandya A, Mistry D, Owens D. Anatomical models versus Nontactile Distanced Learning in Otolaryngology Teaching. Surg J (N Y). 2021;7(3):e259–64. https://doi.org/10.1055/s-0041-1733992.
20. Bao G, Yang P, Yi J, Peng S, Liang J, Li Y, Guo D, Li H, Ma K, Yang Z. Full-sized realistic 3D printed models of liver and tumour anatomy: a useful tool for the clinical medicine education of beginning trainees. BMC Med Educ. 2023;23(1):574. https://doi.org/10.1186/s12909-023-04535-3.
21. Huang Z, Song W, Zhang Y, Zhang Q, Zhou D, Zhou X, He Y. Three-dimensional printing model improves morphological understanding in acetabular fracture learning: a multicenter, randomized, controlled study. PLoS ONE. 2018;13(1):e0191328. https://doi.org/10.1371/journal.pone.0191328.
22. Shapiro L, Hobbs E, Keenan ID. Transforming musculoskeletal anatomy learning with haptic surface painting. Anat Sci Educ. 2023;16(4):677–93. https://doi.org/10.1002/ase.2262.
23. Naug HL, Colson NJ, Donner DG. Promoting metacognition in first year anatomy laboratories using plasticine modeling and drawing activities: a pilot study of the blank page technique. Anat Sci Educ. 2011;4(4):231–4. https://doi.org/10.1002/ase.228.
24. Pandey P, Zimitat C. Medical students' learning of anatomy: memorisation, understanding and visualisation. Med Educ. 2007;41(1):7–14. https://doi.org/10.1111/j.1365-2929.2006.02643.x.
25. Garas M, Vaccarezza M, Newland G, McVay-Doornbusch K, Hasani J. 3D-Printed specimens as a valuable tool in anatomy education: a pilot study. Ann Anat. 2018;219:57–64. https://doi.org/10.1016/j.aanat.2018.05.006.
26. Ye Z, Dun A, Jiang H, Nie C, Zhao S, Wang T, Zhai J. The role of 3D printed models in the teaching of human anatomy: a systematic review and meta-analysis. BMC Med Educ. 2020;20(1):335. https://doi.org/10.1186/s12909-020-02242-x.
27. Reid S, Shapiro L, Louw G. How Haptics and drawing enhance the learning of anatomy. Anat Sci Educ. 2019;12(2):164–72. https://doi.org/10.1002/ase.1807.
28. Sathian K. Tactile sensing of surface features. Trends Neurosci. 1989;12(12):513–9.
29. Sathian K. Analysis of haptic information in the cerebral cortex. J Neurophysiol. 2016;116(4):1795–806. https://doi.org/10.1152/jn.00546.2015.

Publisher's Note