Mind Mapping Anatomical Illustrations: Pilot Evaluation of Paper-and Slide-Based Educational Tools

Conference Paper · September 2025

DOI: 10.2312/vcbm20251249

8 authors, including:

João Afonso
Technical University of Lisbon

Inês Lúcio
Instituto Superior Técnico

Luís Proença
Egaz Moniz School of Health and Science

Daniel Simões Lopes
Instituto Superior Técnico

Eurographics Workshop on Visual Computing for Biology and Medicine (2025)
L. Garrison and R. Krueger (Editors)

Short Paper

Mind Mapping Anatomical Illustrations: Pilot Evaluation of Paper- and Slide-Based Educational Tools

M. Rodrigues[1], J.D. Afonso[1,2], I. Lúcio[1], L. Proença[3], J.J. Mendes[3], P. Rodrigues[3], R.G. Raidou[4], D.S. Lopes[1,2]

[1] Instituto Superior Técnico, Universidade de Lisboa, Portugal [2] ITI / LARSyS, Portugal
[3] Egas Moniz School of Health and Science, Portugal [4] TU Wien, Austria

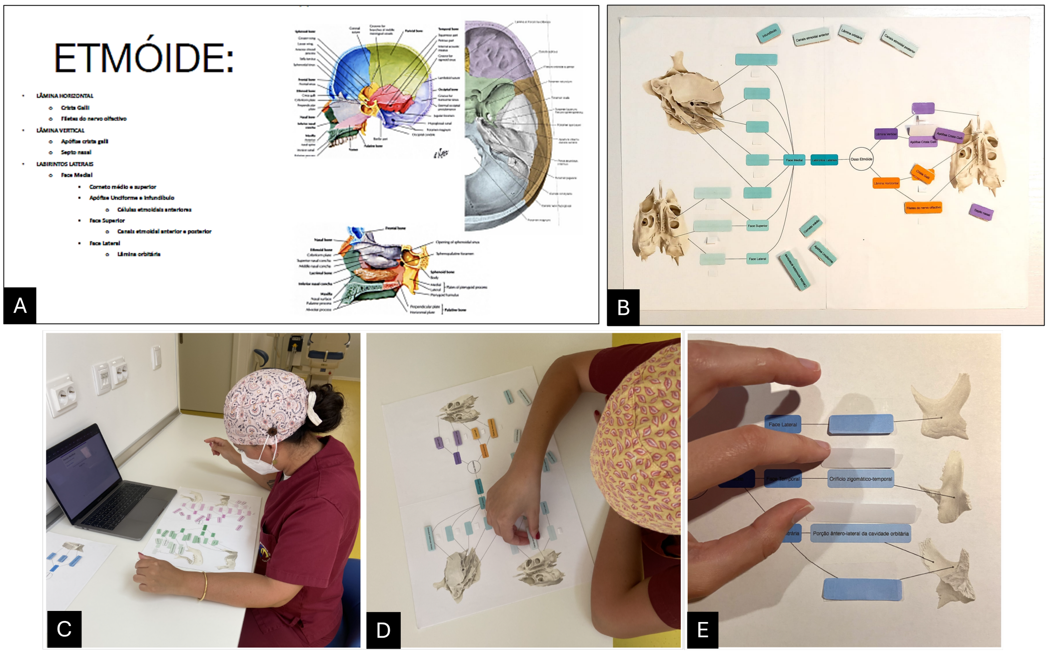

Figure 1: *We introduce a redesigned format to traditional anatomy slides (A) crafted as paper anatomy maps (B,C). These A4/A3-sized cardboard sheets incorporate color-coded adhesive label pieces (D) and foldable flaps (E), functioning as physicalized mind maps that visually organize anatomical illustrations and highlight hierarchical relationships between landmarks. All materials used in the study are available in the Supplementary Materials.*

Abstract

Anatomy is often taught using traditional tools such as PowerPoint slides, which typically feature medical illustrations crowded with colored labels but without a clear representation of how anatomical concepts are interconnected. This is known to overwhelm students and to hinder their ability to understand and retain complex anatomical relationships. In this work, we explore an alternative to traditional slide-based education through the use of physicalized mind maps crafted as paper-based tools that integrate color-coded diagrams with anatomical illustrations, here called paper anatomy maps. Specifically, we conducted co-design sessions with stakeholders to inform the design of the paper-based tool, and subsequently evaluated their potential to enhance engagement and short-term retention in dental students learning skull osteology. A user study involving 30 dental students was conducted to compare PowerPoint slides and paper anatomy maps. While both methods promoted short-term retention, the paper-based format was perceived more positively in terms of usability, cognitive workload, and engagement, suggesting that interactive, hands-on tools like paper anatomy maps can enrich students' anatomy learning experiences.

CCS Concepts

• ***Human-centered computing*** → ***Visualization;*** *Empirical studies in visualization;*

1. Introduction

Anatomy is the foundation of medical education, offering essential knowledge of the human body's structure, function, diseases, and treatments [ARO*24]. However, the vast amount of material makes it difficult for medical students to understand and retain anatomical content. Paradoxically, students often resort to passive learning strategies, focusing on rote memorization rather than engaging with the material meaningfully, causing low retention of information and increased risk of lower academic performance [SGB*14].

Traditional anatomy education methods, such as textbooks and PowerPoint slides, often promote passive learning. While effective for delivering structured content, these approaches typically present information linearly. This format makes it difficult for students to understand the complex network of spatial and functional relationships between anatomical structures and landmarks [Kha17]. As a result, learners may struggle to form meaningful, integrative connections across anatomical systems [Kha17].

To address the complexity of anatomy education, data visualization techniques such mind maps have started to gain traction [TMF21, LRRL24, LBR*24]. Mind maps are tailored to visually organize complex information around a central concept and have been shown to enhance comprehension and long-term memory. Several studies indicate that visual-spatial learning strategies like mind mapping significantly outperform traditional linear note-taking in promoting retention and understanding of complex subjects [DZOC10, FHH02, BSG*18]. Few studies have repurposed mind maps to carry the topological information of an anatomical structure in the shape of interactive experiences in AR [LRRL24] and VR [LBR*24]. While VR and AR tools can improve engagement, they often lack the same level of tactile, tangible interaction provided by data physicalizations [SKRW22]. However, creating such physical representations of data, which offer intuitive and interactive exploration experiences, typically relies on expensive and specialized technologies like 3D printing [PWR21].

Our study addresses a gap in the literature by combining mind maps and anatomical illustrations with low-cost physicalizations. Such tactile educational tools are here called paper anatomy maps. While some previous works have explored paper-based learning aids for anatomy, they do not exploit the potential of mind maps, let alone their integration into illustrations to explicitly depict the hierarchical relationships between anatomical concepts [BSG*18, FHH02, CCG*20, PWR21, SKRW22]. In this study, we aim to evaluate the effectiveness of such mind map physicalizations in improving short-term retention of anatomical knowledge, thus helping students recall and identify anatomical structures, looking at teaching skull osteology to dental students as a case study. We address the following research questions: (**RQ1**) *What are the perceived benefits and limitations of using paper anatomy maps in anatomy education for dental students compared to traditional slide-based tools?* and (**RQ2**) *To what extent do paper anatomy maps support the retention of anatomical concepts compared to traditional slide-based tools?* To this end, we conducted a between-groups user study (N = 30; 15 per group) comparing low-cost paper anatomy maps, which embed mind maps within anatomical illustrations of skull structures, against traditional slide-based learning materials. Our work has two main contributions: (i) we conducted co-design sessions that informed the development of the paper anatomy maps next to anatomy instructors and dental students; and (ii) we explore the potential of these paper-based mind map physicalizations as a low-cost, tactile educational tool to enhance anatomy learning.

1.1. Anatomical Content

The anatomical content used in this study (i.e., through co-design sessions, mind mapping, anatomical illustration, crafting paper tools, final user evaluation) was curated and validated by a head and neck anatomy assistant professor at Egas Moniz School of Health and Science (male; 4 years of experience teaching anatomy). The material consisted of PowerPoint slides systematically organized to emphasize key anatomical features relevant to teaching skull osteology to first and second-year dental students. Each slide included medical illustrations populated with color-coded labels to identify anatomical landmarks (Figure 1). To ensure a representative range of anatomical complexity, we selected three bones of varying structural intricacy: the zygomatic bone (12 labeled landmarks), the ethmoid bone (18 landmarks), and the mandible (27 landmarks), providing a graduated spectrum for assessing the effectiveness of the learning tools. All study materials were written in Portuguese.

1.2. Co-Design Sessions with Design Probes

As part of an informal design probe, we introduced early versions of physicalized mind map tools to both anatomy professors and dental students, collecting feedback to inform our design direction.

The first co-design session was conducted with three first-year dental students (female, age 19; female, age 20; male, age 19) and two anatomy professors (male, age 35; male, age 45), who evaluated a design probe in the form of an Anatomy Model Cube (Figure 2 (A)). This prototype was designed to support students in recalling and identifying skull structures by providing a multi-angled, spatial overview of skull anatomy and enhancing their understanding of anatomical relationships. The Anatomy Model Cube was a paper-based tool constructed from eight smaller blocks arranged in a 2×2×2 configuration and strapped to each other in a way that allowed them to unfold, enabling users to explore multiple 2D views of the skull. Each face displayed a medical illustration labelled with anatomical landmarks. On the reverse side, the cube revealed an eight-piece puzzle of a skull anatomy mind map. This side included placeholders where users could attach the squared puzzle pieces, using adhesive putty, to rebuild the entire mind map (Figure 2 (B)).

Participants recommended enlarging the cube for easier handling and raised concerns about the clarity of the mind map presentation. They also expressed a dislike for assembling the mind map from separate square pieces, suggesting instead a more structured layout in the form of a mind map with blank placeholders to fill in, allowing for more focused educational activity. Students also noted that the number of labels was somewhat overwhelming, making the tasks time-consuming. Notably, participants pointed out the absence of a clear, explicit visual connection between the mind map and the anatomical landmarks shown in medical illustrations.

Based on feedback from the first session, a second co-design session was conducted, with two new design probes (Figure 2 (C,D,E) and Figure 2 (F)). The cube shaped prototype was an enlarged version of the original cube (Figure 2 (A)), designed for easier handling and improved visibility. This version unfolded into a flat 2D surface, allowing users to view the entire mind map at once, directly addressing concerns about clarity. The mind map included color-coded unlabeled nodes, prompting students to actively place the correct labels, maintaining interactivity while enhancing organization and comprehension. The second prototype departed from the cube format entirely, presenting a flat 2D board that directly integrated anatomical illustrations into the mind map structure. Each leaf of the mind map was visually linked to an illustration of the corresponding bone, creating an explicit connection between concepts and anatomical landmarks. This probe also featured color coding and placeholders for labels. Its purpose was to evaluate whether embedding anatomical illustrations within the mind map would improve comprehension and retention than separating them, as in the cube-based model.

A second feedback session was conducted with three first-year dentistry students. The updated cube prototype received mixed reactions: while students appreciated its tactile and interactive qualities, they found the unfolded graph too small, which hindered both interaction and comprehension. The 2D cardboard prototype was received more favorably, with students valuing the integration of anatomical illustrations directly within the mind map, noting that this approach helped organize and reinforce anatomical knowledge (Figure 2 (F)). The color-coded structure helped users better understand the content, allowing for more precise labeling and clearer information structuring. Additionally, participants recommended including a solution guide or reference key, as some struggled to recall specific terms and were unsure whether they had labeled the nodes correctly, enhancing the tool's educational utility.

1.3. Mind Mapping Anatomical Illustrations

Based on the labeled content from the PowerPoint slides, we wrote marked-up text files encoding both the label strings and their semantic connections. These files explicitly defined the structure of mind maps representing the relationships between anatomical landmarks. The data were then processed using a custom Python script (Python 3.9.4) to generate vector-based diagrams (*.svg) containing labeled nodes, placeholder nodes, and connecting edges that were rendered in Graphviz (v2.49.3). Each node represents an anatomical structure or surface, with its size dynamically adjusted based on the label's length to enhance readability and usability. These graphical mind maps provided a visual overview of the hierarchical structure of anatomical relationships, i.e., excluding medical illustrations. Each mind map was structured around a central node representing the main anatomical concept of the bone, with branches extending to leaf nodes corresponding to specific anatomical landmarks. Primary branches stemming from the central node were assigned distinct colors to differentiate between regions of the bone. Child nodes inherited the color of their parent, rendered with progressively lower opacity, creating a gradient effect that reinforces structural understanding. The color palette was carefully selected using analogous color schemes to ensure visual harmony and maintain a cohesive design. To ensure accessibility for individuals with color vision deficiency, all color choices were verified using the Color Blindness Simulator [Col16].

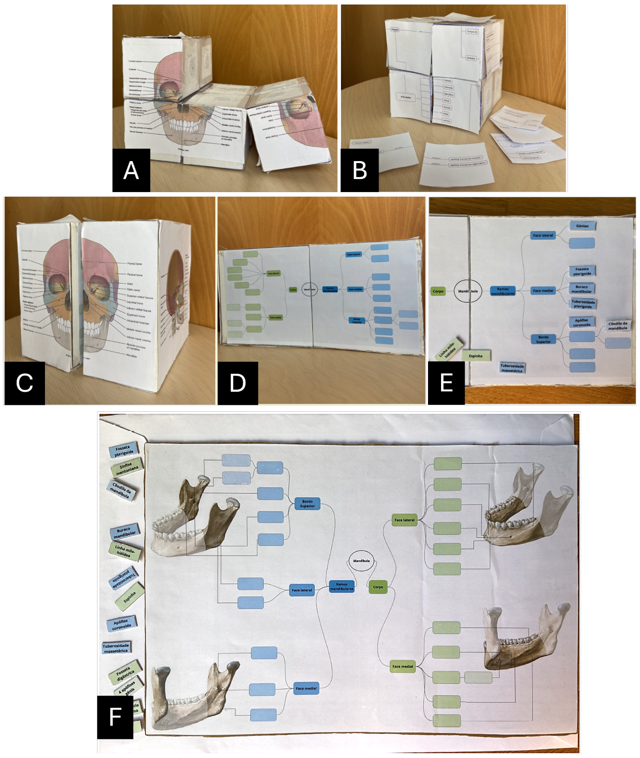

Figure 2: *Paper-based design probes used during co-design sessions: (A) 1st iteration of an Anatomy Model Cube with an (B) anatomy map puzzle cut into 8 equally sized pieces; (C) 2nd iteration of the Anatomy Model Cube (D) that unfolds to reveal an anatomy map (E) with placeholders to stick colored label pieces (E); and (F) A4-sized paper anatomy map presenting a mind map branching out label placeholders (i.e., leaves) that become anchored to anatomical illustrations.*

Using the open-source vector graphics editor Inkscape (version 1.4 beta), the mind maps and anatomical illustrations were manually integrated into single canvases. Skull bone illustrations were sourced from the Anatomy Standard database [Sav23]. In the final designs, the terminal nodes of each mind map were connected to corresponding anatomical structures on the unlabeled bone illustrations using directional arrows. Each bone was depicted from multiple anatomical views to accurately highlight the surfaces where the labeled landmarks are located.

1.4. Crafting Paper Anatomy Maps

Each paper anatomy map was printed on A4 white paper sheets and mounted onto A4 or A3 cardboard sheets to enhance durability and facilitate handling. To support interactive learning, two types of placeholder mechanisms were introduced. The first consisted of individual labeled rectangular pieces mounted on laminated cardboard and backed with adhesive putty to allow easy attachment and repositioning on the paper sheet. The second involved flap mechanisms, created by attaching paper flaps to the sheet using duct tape, which concealed the correct labels beneath

Proceedings published by Eurographics - The European Association for Computer Graphics.

each unlabelled node. This format offers immediate feedback, enables self-assessment, and promotes active engagement, factors known to enhance the retention of complex anatomical content [SGB*14, CCG*20, CMM17]. In both formats, the elements corresponding to the final nodes were printed separately to allow hands-on engagement with the material. The primary objective for users is to complete each mind map by correctly matching the color-coded labels to their corresponding anatomical structures.

1.5. User Studies

We conducted a user study involving 30 fifth-year Master's students in Dentistry (22 female, 8 male; age range: 21–45, M = 24.47, SD = 5.04). Of these, 26 reported previous use of mind maps or other schematic tools for studying anatomy, and an equal number indicated experience with physical study aids such as 3D anatomical models and bone specimens. The study assessed pre-quiz versus post-quiz performance, usability, and engagement using two independent variables: instructional method (paper anatomy map vs. traditional PowerPoint slides) and task complexity, determined by three skull bones of increasing difficulty (low: zygomatic; intermediate: ethmoid; high: mandible). Dependent variables included knowledge retention (measured through pre- and post-quizzes), perceived usability, cognitive workload, and user engagement.

Participants were divided into two groups of 15: the experimental group used the paper-based mind map tool, which involved actively completing the anatomy maps, while the control group reviewed traditional PowerPoint slides. Each study session lasted 10 minutes, after which participants completed a five-question multiple-choice quiz to assess knowledge retention. Participants began by signing an Informed Consent form outlining the study's goals and procedures and completed a demographic questionnaire capturing gender, academic background, prior anatomy experience, and familiarity with mind maps and physical tools. A brief habituation task was conducted to familiarize participants with the educational format. Each participant then performed three main tasks, one per skull bone, presented in an order counterbalanced using a Latin Square design to control for sequence effects. Each task began with a pre-quiz, followed by a 10-minute study period, and concluded with a post-quiz identical to the pre-quiz to evaluate knowledge gain. After completing all tasks, participants filled out the System Usability Scale (SUS), NASA Task Load Index (NASA-TLX), and User Engagement (UE) questionnaires. Finally, semi-structured interviews gathered qualitative feedback on perceived effectiveness, usability issues, and suggestions for improving both educational methods.

2. Results

2.1. User experience evaluation

Three standardized questionnaires were used to evaluate overall user experience: SUS, NASA-TLX, and UE. In terms of perceived usability, the paper anatomy map group scored higher (M: 90.33, SD: 6.47) than the slide group (M: 69.00, SD: 16.79). For perceived physical and cognitive workload, the paper anatomy map group reported lower demands (M: 31.39, SD: 12.36) compared to the slide group (M: 46.11, SD: 14.12). Engagement scores were also higher in the paper anatomy map group (M: 125.07, SD: 11.65) versus the slide group (M: 91.10, SD = 21.50).

2.2. Users' verbal feedback

After completing the quizzes, we conducted semi-structured interviews to explore participants' perceptions of the educational tools they used. The questions evaluate the perceived value and limitations of the paper anatomy maps as either a complementary or alternative method to traditional approaches. Regardless of the type of tool they tested, participants were asked to identify beneficial features, describe any difficulties or limitations they encountered, suggest improvements, and reflect on how the tool affected their engagement and enjoyment. For the slide group, additional questions focused on their overall experience, the perceived effectiveness of slides in reinforcing anatomical content, and recommendations for enhancing conventional learning approaches.

In the paper anatomy map group, 6 participants regarded the mind maps integrated into anatomical illustrations as a strong alternative to traditional methods, citing its interactivity and engaging design. One remarked, "*It's more interactive and keeps me focused better than traditional methods.*" However, 8 others viewed it as a complementary learning tool, pointing to the absence of detailed anatomical data and 3D perspectives. All participants noted that color coding aided memory by visually segmenting skull regions. Thirteen praised the mind map format for organizing content hierarchically, which could help them with oral exam preparation. Eleven highlighted the benefits of tactile interaction, saying it enhanced retention over digital tools. Eight appreciated the labeling activity, mentioning it as a reinforcing learning task. Still, 7 noted that differently sized pieces made tasks too easy, reducing the cognitive challenge. One commented, "*The size helps, but it doesn't challenge me enough to retain it long term.*" Four participants missed having a 3D representation, stating that it hindered spatial understanding of complex bones.

The slide group responses were mixed. Six found slides familiar and straightforward, but admitted they lacked comprehensive views of the bones. Nine reported difficulties, citing low interactivity and the absence of 3D visuals as barriers to comprehension and retention. Several found the format monotonous and struggled to focus. Participants noted slides were text-heavy and less effective than tactile methods like note-taking. When asked about suitability for refreshing concepts, 10 out of 15 deemed slides insufficient due to limited visual depth. Notably, 14 of 15 participants believed a physicalization tool would enhance learning by making study more tangible, engaging, and effective.

2.3. Pre-quiz versus post-quiz performance

Participants' knowledge retention was evaluated before and after using the educational tools through pre-test and post-test scores for three bones of varying complexity (Table 1). We then ran ran a factorial repeated-measures ANOVA analysis and assessed the effect of group (paper anatomy map vs. slide) and task complexity on learning performance. Results revealed no statistically significant differences between the two groups ($p = 0.342$), hence, no

Table 1: *Differences between post-quiz and pre-quiz scores (range 0-5) versus task complexity (low: zygomatic; intermediate: ethmoid; high: mandible). Presented as Mean (SD). **Factorial RM ANOVA, accounting for group type and task complexity interaction effect. The factor 'task complexity' is shown to be significant (p=0.016) (mandible vs. zygomatic/ethmoid).*

Group	Zygomatic	Ethmoid	Mandible	p^{**}
Paper Anatomy Map	2.8 (0.6)	3.1 (1.3)	1.9 (0.8)	0.342
Slide	2.9 (1.3)	2.6 (1.2)	2.3 (1.3)	

meaningful difference was detected regarding knowledge retention between the paper anatomy maps and slides.

3. Discussion

Our pilot evaluation revealed encouraging qualitative feedback alongside less conclusive quantitative outcomes. User experience metrics and qualitative feedback indicated that students generally found the paper anatomy maps engaging, usable, and less cognitively demanding. These observations support a positive answer to **RQ1**, suggesting that paper anatomy maps can provide added value in terms of learner experience and may serve as a complementary tool rather than a replacement for existing methods. Overall, these findings highlight the potential of tactile, paper-based educational tools that integrate color-coded mind maps with anatomical illustrations to enhance the student learning experience. However, no statistically significant differences in knowledge gain were observed between students using paper anatomy maps and those using traditional slide-based tools, so we are unable to draw conclusions regarding **RQ2**. Such a null result may be explained by factors such as the relatively small sample size, the restricted focus on skull osteology, the potential novelty effect of the physicalization, and differences in prior familiarity with mind maps. Despite the co-design sessions guiding the development of the paper anatomy maps, this pilot evaluation represents an initial step toward future studies that should involve larger-scale studies with more diverse cohorts (i.e., long-term studies lasting a full academic year involving more participants) and more complex anatomical content to determine whether the observed user experience benefits persist beyond novelty and translate into long-term learning gains. Finally, users' verbal feedback points to an interesting research opportunity as paper anatomy maps could be extended to incorporate more 3D content, thus, paving the way for touch-screen or even immersive (e.g., augmented/mixed reality) mind map applications. Such approaches could be combined with traditional learning aids, including real bone specimens or plastic 3D models, to create richer, multimodal anatomy learning experiences.

4. Acknowledgements

The authors acknowledge the Portuguese Recovery and Resilience Program (PRR) for its financial support via IAPMEI/ANI/FCT under Agenda C645022399-00000057 (eGamesLab) and Fundação para a Ciência e a Tecnologia through projects 10.54499/LA/P/0083/2020, 10.54499/UIDP/50009/2020, and 10.54499/UIDB/50009/2020.

References

[ARO*24] ALTURKUSTANI S., RYAN S. M., O'MAHONY S. M., TOULOUSE A., O'MAHONY C., LONE M.: Comparison of "complete anatomy" (CA) to conventional methods for teaching laryngeal anatomy to first-year dental and dental hygiene students in ireland. *Translational Research in Anatomy 37* (July 2024), 100324–100324. doi:10.1016/j.tria.2024.100324. 2

[BSG*18] BASAVARAJ P., SINGLA A., GUPTA R., MALHI R., CHAUDHARY D.: Effectiveness of mind mapping as a learning tool among dental students. *Journal of Indian Association of Public Health Dentistry 16* (May 2018), 122–126. doi:10.4103/jiaphd.jiaphd_23_18. 2

[CCG*20] CARDOZO L. T., CASTRO A. P., GUIMARÃES A. F., LUDMILA L., MONTREZOR L. H., MARCONDES F. K.: Integrating synapse, Muscle contraction, and Autonomic nervous system game: Effect on learning and evaluation of students' opinions. *AJP Advances in Physiology Education 44*, 2 (Mar. 2020), 153–162. doi:10.1152/advan.00169.2019. 2, 4

[CMM17] CRISTINA K., MONTREZOR L. H., MARCONDES F. K.: Effect of an educational game on university students' learning about action potentials. *AJP Advances in Physiology Education 41*, 2 (Apr. 2017), 222–230. doi:10.1152/advan.00146.2016. 4

[Col16] COLBLINDOR: Coblis — color blindness simulator, 2016. Accessed: 20 May 2025. URL: https://www.color-blindness.com/coblis-color-blindness-simulator/. 3

[DZOC10] D'ANTONI A. V., ZIPP G. P., OLSON V. G., CAHILL T. F.: Does the mind map learning strategy facilitate information retrieval and critical thinking in medical students? *BMC Medical Education 10*, 1 (Sept. 2010). doi:10.1186/1472-6920-10-61. 2

[FHH02] FARRAND P., HUSSAIN F., HENNESSY E.: The efficacy of the 'mind map' study technique. *Medical Education 36*, 5 (May 2002), 426–431. doi:10.1046/j.1365-2923.2002.01205.x. 2

[Kha17] KHALIFA N. A.: *Use of Mind Mapping (MM) as an Unconventional Powerful Study Technique in Medical Education*. Springer International Publishing, Cham, 2017, pp. 119–133. doi:p36w. 2

[LBR*24] LÚCIO I. M., BERNARDO, RAIDOU R. G., PROENÇA L., ZAGALO C., MENDES J. J., RODRIGUES P., LOPES D. S.: Knowledge maps as a complementary tool to learn and teach surgical anatomy in virtual reality: A case study in dental implantology. *Healthcare Technology Letters 11*, 6 (Nov. 2024), 289–300. doi:10.1049/htl2.12094. 2

[LRRL24] LÚCIO I. M., RAIDOU R. G., RODRIGUES P., LOPES D. S.: Your face, Your anatomy: Flashcard lenses enriched with knowledge maps for anatomy education. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (2024), pp. 495–504. doi:10.1109/ISMAR62088.2024.00064. 2

[PWR21] PAHR D., WU H.-Y., RAIDOU R. G.: Vologram: An Educational Holographic Sculpture for Volumetric Medical Data Physicalization. In *Eurographics Workshop on Visual Computing for Biology and Medicine* (2021), Oeltze-Jafra S., Smit N. N., Sommer B., Nieselt K., Schultz T., (Eds.), The Eurographics Association. doi:10.2312/vcbm.20211341. 2

[Sav23] SAVLOVSKIS J.: Anatomy standard landing page, 2023. Accessed: 10 May 2025. URL: https://www.anatomystandard.com/. 3

[SGB*14] SAMAGA M. P., GUDI N., BHAT S. M., BHASKAR N., SULIANKATCHI R. S.: Mind map: Medical student's views. *Indian Journal of Pharmacy and Biological Research 2*, 4 (2014), 58–60. 2, 4

[SKRW22] SCHINDLER M., KORPITSCH T., RAIDOU R. G., WU H.-Y.: Nested papercrafts for anatomical and biological edutainment, 2022. arXiv preprint. doi:10.48550/arXiv.2204.10901. 2

[TMF21] TAVARES L. A., MEIRA M. C., FERREIRA S.: Interactive mind map: A model for pedagogical resource. *Open Education Studies 3*, 1 (Jan. 2021), 120–131. doi:10.1515/edu-2020-0145. 2