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"Visualization matters" – stereoscopic visualization of 3D graphic neuroanatomic models through *AnaVu* enhances basic recall and radiologic anatomy learning when compared with monoscopy

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Abstract

Background The authors had previously developed *AnaVu,* a low-resource 3D visualization tool for stereoscopic/monoscopic projection of 3D models generated from pre-segmented MRI neuroimaging data. However, its utility in neuroanatomical education compared to conventional methods (specifically whether the stereoscopic or monoscopic mode is more effective) is still unclear.

Methods A three-limb randomized controlled trial was designed. A sample ($n = 152$) from the 2022 cohort of MBBS students at Government Medical College, Thiruvananthapuram (GMCT), was randomly selected from those who gave informed consent. After a one-hour introductory lecture on brainstem anatomy and a dissection session, students were randomized to three groups (S – Stereo; M – Mono and C – Control). S was given a 20-min demonstration on the brainstem lesson module in *AnaVu* in stereoscopic mode. M was given the same demonstration, but in monoscopic mode. The C group was taught using white-board drawn diagrams. Pre-intervention and post-intervention tests for four domains (basic recall, analytical, radiological anatomy and diagram-based questions) were conducted before and after the intervention. Cognitive loads were measured using a pre-validated tool. The groups were then swapped -S⟶ M, M ⟶S and C⟶S, and they were asked to compare the modes.

Results For basic recall questions, there was a statistically significant increase in the pre/post-intervention score difference of the S group when compared to the M group [$p = 0.03$; post hoc analysis, Bonferroni corrections applied] and the C group [$p = 0.001$; ANOVA test; post hoc analysis, Bonferroni corrections applied]. For radiological anatomy questions, the difference was significantly higher for S compared to C [$p < 0.001$; ANOVA test; post hoc analysis, Bonferroni corrections applied]. Cognitive load scores showed increased mean germane load for S (33.28 ± 5.35) and M

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(32.80 ± 7.91) compared with C (28.18 ± 8.17). Subjective feedbacks showed general advantage for S and M compared to C. Out of the S and M swap cohorts, 79/102 preferred S, 13/102 preferred M, and 6/102 preferred both.

Conclusions *AnaVu* tool seems to be effective for learning neuroanatomy. The specific advantage seen when taught with stereoscopy in basic recall and radiological anatomy learning shows the importance of how visualization mode influences neuroanatomy learning. Since both S and M are preferred in subjective feedbacks, these results have implications in choosing methods (stereoscopic – needs 3D projectors; monoscopic – needs web based or hand-held devices) to scale *AnaVu* for anatomy teaching in medical colleges in India. Since stereoscopic projection is technically novel and cost considerations are slightly higher compared to monoscopic projection, the specific advantages and disadvantages of each are relevant in the Indian medical education scenario.

Keywords Anatomy education, Stereoscopic projection, Technology enhanced learning, Monoscopic projection, Computer assisted learning, Anatomical visualization, Spatial learning, Neuroanatomy

Background

Neuroanatomy is considered by learners as both a fascinating and yet a daunting subject when compared with other anatomy topics, such as musculo-sketetal, gastro-intestinal, cardiovascular, respiratory and pelvic-reproductive anatomy [1]. It is complex because of inherent spatial intricacies and numerous terminologies [2] and requires strong spatial reasoning and abstract mental visualization to master it [3]. This skill, referred to as spatial anatomy learning, is usually dependent on a learner's spatial ability [4, 5], and can affect learner's performance in assessments [6]. Though it is often taught during dissection with simple 2D sections of human donor brain [7, 8], learning neuroanatomy requires students to "reconstruct" complex 3D mental images from these sections [9]. For instance, neuroanatomy of brainstem, in particular is difficult to conceptualize due to close proximity of diverse structures (nuclei and tracts), a relatively small volume of tissue [3, 10] and difficulty in visualization of the internal features of brainstem despite its clinical importance [1].

This complexity of learning neuroanatomy is a significant contributor to 'Neurophobia' [11], the fear of learning neural sciences, a term introduced to medical literature in the 1990s. This global phenomenon has effects even on career choices, which creates a negative impact on delivery of neurological healthcare, particularly in India [9]. One of the goals of the Indian anatomy teacher will be to modify the 'neurophobia' of students to 'neurophilia' (love for neural sciences; 'philia' is the Greek for love or affection) [9, 12]. The two hurdles that anatomists face in neuroanatomy teaching in India are—the shrinking time allocation for neuroanatomy [2] and the problem of students' difficulty to "mentally convert" the 2D structures to 3D structures and vice-versa [2]. The examination patterns in India, and hence most of the textbooks in neuroanatomy, demand that students prove their 2D perception, but unfortunately, the emphasis on spatial understanding is not catered to [2]. There have been diverse attempts to simplify learning complex neuroanatomical areas like the brainstem [13–15]. To enhance teaching–learning effectiveness, devising innovative technological solutions to aid the student's process of creating mental 3D images from sections has also been suggested in the global and Indian medical education context [2, 9].

Role of integrating radiological anatomy in neuroanatomy teaching

Though anatomy curriculum has classically followed a combination of lectures and human donor dissections, in the current era, the best teaching model is said to be one where human donor dissection and radiologic imaging are incorporated [16]. The gains of radiology integration to anatomy are multifold with better clinical application of anatomy, increased interest of students in anatomy and eventually better radiological interpretation during their practice [17]. It is suggested that familiarizing students with radiological images earlier on, in their medical education, can significantly improve the student's ability to learn neuroanatomy [18]. Complementing dissection with radiological anatomy can also help students develop spatial reasoning skills [19].

Stereoscopy vs monoscopy in anatomy learning environments

Stereopsis is a binocular sensory phenomenon and is the result of a slight disparity of visual perception of both eyes [20]. Stereopsis plays a key role in spatial understanding by providing depth cues for the viewer. Some studies have indicated that the learning advantage of a simple physical object (e.g., a dissection specimen, a manikin or an anatomical model of an organ) is mainly due to the stereoscopy offered by it, which highlights the central relevance of stereopsis even in a physical laboratory experience [21]. Stereoscopy is utilized in dissection lab specimens or manikins, as these are usually within one's *personal space,* which is considered as the "zone immediately surrounding the observer's head, generally within arm's reach and slightly beyond, within a 2 m radius which is considered quite personal" [20].

Stereopsis can be utilized in 3D visualization technologies by presenting two 2D images in a slightly shifted manner to the two eyes, creating the binocular disparity. Different methods can be utilized for this purpose, including active stereopsis where there is dual projection to the eyes, but no depolarization. Here head gear devices such as Oculus Rift™ through virtual reality [22] or Microsoft HoloLens™ through interactive augmented reality [23] are used. These provide excellent stereoscopic imagery and an immersive experience. These methods are limited, however, by the fact that they are suitable for a single or at most a few students and are expensive [a high-end VR hardware, computer and headset costing nearly \$3000 (INR ~ 2.5 Lakhs)] [24]. This is not typically suitable (economically and logistically) for a large group teaching setting typically seen in the Indian medical education context [25] or other similar low- and middle-income country settings [26].

Another method is using 3D polarizing glasses, where the basic mechanism is that the 3D polarizing glasses would "organize" the polarization given by the projectors and the silver screen, like the one used here in *AnaVu* (vide infra). This is known as passive stereopsis (double depolarization for each eye) and the observer's visual perception interprets the two images as a single 3D image. Here, the limiting factor is only the need for specialized projection systems (stereoscopic projection), as it cannot be displayed on normal projection systems.

Although such constraints are a reality, having a stereo display creates an advantage of delivering stereopsis to the *Action space*– a circular region of radius 2 m to 30 m, beyond the *personal space* of the learner (vide supra) [20]. This opens up an avenue to teach a larger audience. Stereoscopic visualization has advantages in any field where spatial anatomical understanding is critical [27], and hence, this can be a potential scalable solution to the problem of teaching spatial anatomy to a large cohort of medical students.

On the other hand, monoscopy is the presentation of the same image in front of each eye. This is what is seen in a routine projection of images, videos or animations, using classic projectors on a flat screen, which are almost universally available in academic institutions. Although monoscopic presentations do not give depth perception, some static images (e.g., 3D computer models, artistic renderings in anatomy diagrams) may sometimes offer monoscopic cues for minor depth perception [28]. In videos, animations or interactive 3D models, these monoscopic cues may further include perspective projection, shadings, occlusion, motion perspective, and familiar size [20, 29]. Hence, there is a need for evidence as to whether monoscopic mode is as good as stereoscopic mode or whether stereoscopy has definite advantages. This can have implications on how a 3D visualization tool like *AnaVu* (vide infra) needs to be scaled for better learning experience.

Cognitive loads in instructional design

Any multimedia tool in anatomy needs to effectively impact on cognitive loads and instructional design can be conducted in accordance with it [30]. Cognitive load theory (developed by Sweller in 1980s [31] and later revisited by Meyer [32]), is concerned with creating scientifically sound instructional design that will be congruent to the dynamics of the human cognitive system dealing with memory. As new information is always processed by the limited working memory, mediating cognitive load should be in mind when designing a multimedia content in anatomy for the purpose of teaching [30]. They further mention that measurement of cognitive loads of such tools enables it to developers and engineers to design effective and efficient multimedia learning environments and thus is relevant for the new tool *AnaVu* (vide infra) [33]. As per the cognitive load theory, an instruction imposes three types of cognitive loads on a learner's cognitive mechanism – the intrinsic load (IL), the extrinsic load (EL) and the germane load (GL). The IL is influenced by the learner's prior knowledge and the inherent complexity of the task and is not generally dependent on the instructor or the mode of the instruction. GL also known as generative load is concerned with mental organization of learned material, integration with the students mental schema, and pre-existing knowledge [30]. The EL or extraneous load contains materials, approaches of the educator that does not consider the limitations of the learner's working memory limitations. EL thus will lead to learner confusion along with frustration. Components of instructions that are beneficial generally increase the GL, and features that are not beneficial increase the EL. The goal of an educator while designing their lesson would be to moderate the IL, reduce the EL and encourage learning environments to increase GL. This applies while designing an anatomical multimedia [30]. If IL is optimal (which means the right complexity of the task to the right learner) and EL is low, learners can impose GL and engage in activities that elaborate their knowledge and facilitate learning [34]. To summarize – *Less* is always *more* – *less* cognitive load, means *more* learning [30].

AnaVu – a 'homegrown' tool for Anatomy viewing

The authors had previously developed a 'homegrown' tool – *AnaVu*, a scalable solution for visualizing stereoscopic images of anatomical 3D models suitable for low

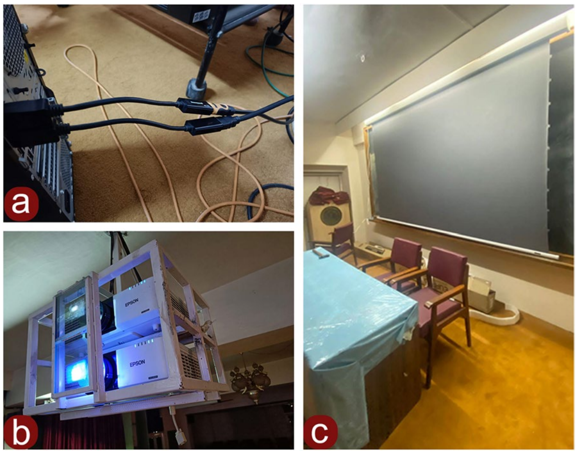

Fig. 1 Hardware of *AnaVu*. **a** Showing the dual output through HDMI from the CPU used for the *AnaVu* software system. **b** Showing the two projectors stacked one above the other, mounted within a projector cage. Polarization filters are also seen in front of the projectors. **c** Showing the silver screen used for the stereoscopic projection

resource settings. The tool has a software-graphic interface for the teacher to operate on and a hardware capable of stereoscopic visualization, which consisted of two HDMI outputs (Fig. 1a). These outputs channel two separate images for projection to two projectors stacked one above the other in a metallic projector cage (see Fig. 1b). These had polarization filters in front of the projectors which could project two images with binocular disparity to simulate stereopsis on a silver screen (Fig. 1c). The teacher and the students could visualize the 3D model on the silver screen using 3D glasses, in a dark room setting (passive stereopsis – vide supra). These 3D models were pre-segmented from MRI images (by manual and automated segmentation), which involves identifying and separating distinct subsections of the anatomy based on grayscale values in a particular voxel (3D equivalent of a pixel in a 2D image) and a knowledge of the anatomical structure and its location [35] as done in other studies [36]. More technical details of the segmentation and the projection system can be seen in [37]. *AnaVu* can be used to give a comprehensive experience of learning anatomy visually by presenting surface features of segmented modes as in solid anatomical models. 3D spatial understanding can also be cultivated as radiological anatomy is also simultaneously presented in orthogonal MRI sections similar to "The Divisible Human" model reported by Rizzolo et al. [38]). The features of *AnaVu* are shown in Figs. 2 and 3, in the visualization of brainstem.

During its development, scaling of the tool as a large group teaching aid (in stereoscopic mode) and also for possible self-directed learning (in monoscopic mode) was in mind. Hence *AnaVu* was equipped with a feature to shift between a stereoscopic and monoscopic modes of visualization. Parallel to the present study, utility of *AnaVu* stereoscopic tool from a teacher's perspective was evaluated among a small cohort of Anatomy teachers [39]. Though it indicated general appreciation and utility in teaching spatial anatomy, there were also critical feedback such as lack of interaction with students, eye strain and need for training, when using stereoscopic mode.

The graphic user interface of *AnaVu* was designed in such a way that it has functionalities aiding effective anatomical pedagogy. It was a three-panel design with a 3D viewport in its center (see Fig. 2), which allowed for selection of an object, a free trackball rotation, zoom in/out, and panning (see Fig. 3). In the right panel, there were three canonical section (sagittal, axial and coronal) MRI images (each containing an image stack). The image stack could be surveyed by scrolling in that image/sliding the slider on the right panel. The planes of these sections were also present in the 3D viewport. This gave the teacher and the student the option to understand the correlation between the 3D model and the 2D MRI section (see Fig. 2). If the teacher wished to lay focus on the MRI section image, then that could be swapped with the image on the central 3D viewport. This option was created because neuroanatomy is often taught through sections. In the left panel, there were the list of structures, controls and 'buttons' for selecting lessons, selecting/deselecting planes, manipulating opacity, and switching to canonical anatomical views (Left/Right, Superior/Inferior, Anterior/Posterior). There were also options to select objects and reduce opacity to "see through" or "within" a structure (See Fig. 3). An exemplar video on how this tool can be used in teaching is made available on YouTube (https://youtu.be/Q_T-vY9Kli8?si=A0SKbZRFKG8aL1I7).

AnaVu has a labelling option where you can click on any object that you see in the 3D viewport which will show the structure highlighted in the 3D viewport with a label popped up (See Fig. 2, where globus pallidus is clicked and the label comes up). And the relations with the putamen laterally can be visualized in the 3D viewport as well as the sections.

AnaVu also provides a feature to switch between a stereo mode and a mono mode making it suitable for settings where the stereoscopic projection system is not feasible. This gave the teacher the freedom to teach using *AnaVu* along with a regular PowerPoint presentation or to have a standalone stereoscopic presentation.

Though these functionalities seem promising, the utility of such a tool, compared to traditional methods in anatomical pedagogy is not known in a large group setting. Since 3D graphic models in monoscopy can have

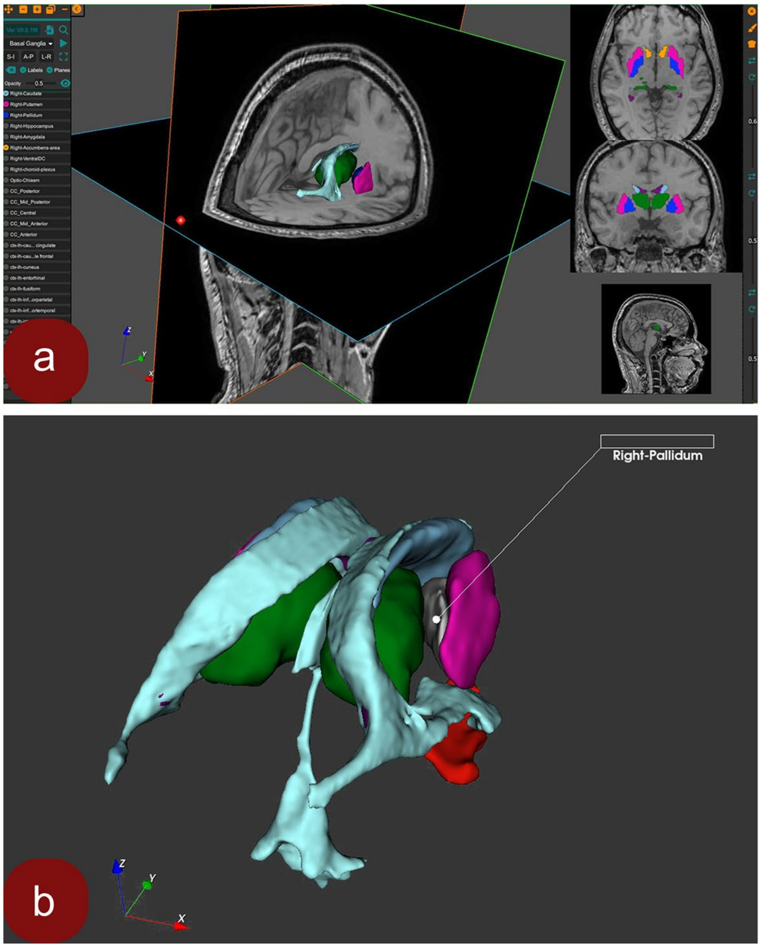

Fig. 2 Screenshots from *AnaVu* user interface. **a** Shows the graphic user interface of *AnaVu*, which consists of 3 main vertical panels. The basal ganglia and the ventricles are visualized in the middle and right panels. Left panel shows the 'buttons' and controls for selecting lessons, structures, modifying opacity, and selecting monoscopic or stereoscopic visualisation modes. Middle panel shows the 3D viewport for 3D image demonstration. Right panel shows the three canonical 2D sections (axial, coronal, and sagittal sections of T1-MRI images) in that order from top to bottom, and the 2D sections of the 3D model (shown in the middle panel) colored correspondingly. These sections are scrollable by cursor. **b** Shows the right globus pallidus (pallidum) being selected when the label pops up

some depth cues, as mentioned before, it is also not known whether that would suffice to improve spatial learning. Hence, the possibility of spatial learning of a 3D model projected non-stereoscopically (monoscopy) needs to be understood. Moreover, if monoscopic visualization of the 3D model is more or even as effective as stereoscopic visualization of the same model, then the translation of the model into web-based platforms will be useful, as it can be visualized in hand-held devices. It is also interesting to know, as these tools are made from radiologic (MRI) resources, whether these can be used to teach important domains like basic recall and higher analytical learning, its role in teaching radiological anatomy and its impact on diagram-based questions (common in

(See figure on next page.)

Fig. 3 Figure panel showing the functionalities of *AnaVu*. **a** Showing a 3D right antero-lateral view of the brainstem and spinal cord along with its different parts highlighted using distinct colors. **b** Showing an MRI of the axial section of the brainstem at the level of midbrain in the central panel with the 3D image of the same in the right panel. **c** Showing a 3D postero-supero-lateral view of the midbrain and pons. Better visualisation of the internal structures has been ensured by the reduction of opacity of the gross framework of midbrain. **d** Showing the 3D posterior view of the pons and medulla. Opacity of the part of pons and medulla has been reduced to show the internal structures. (The above pictures are screenshots from *AnaVu*. All labellings in this figure have been made using Adobe Photoshop)

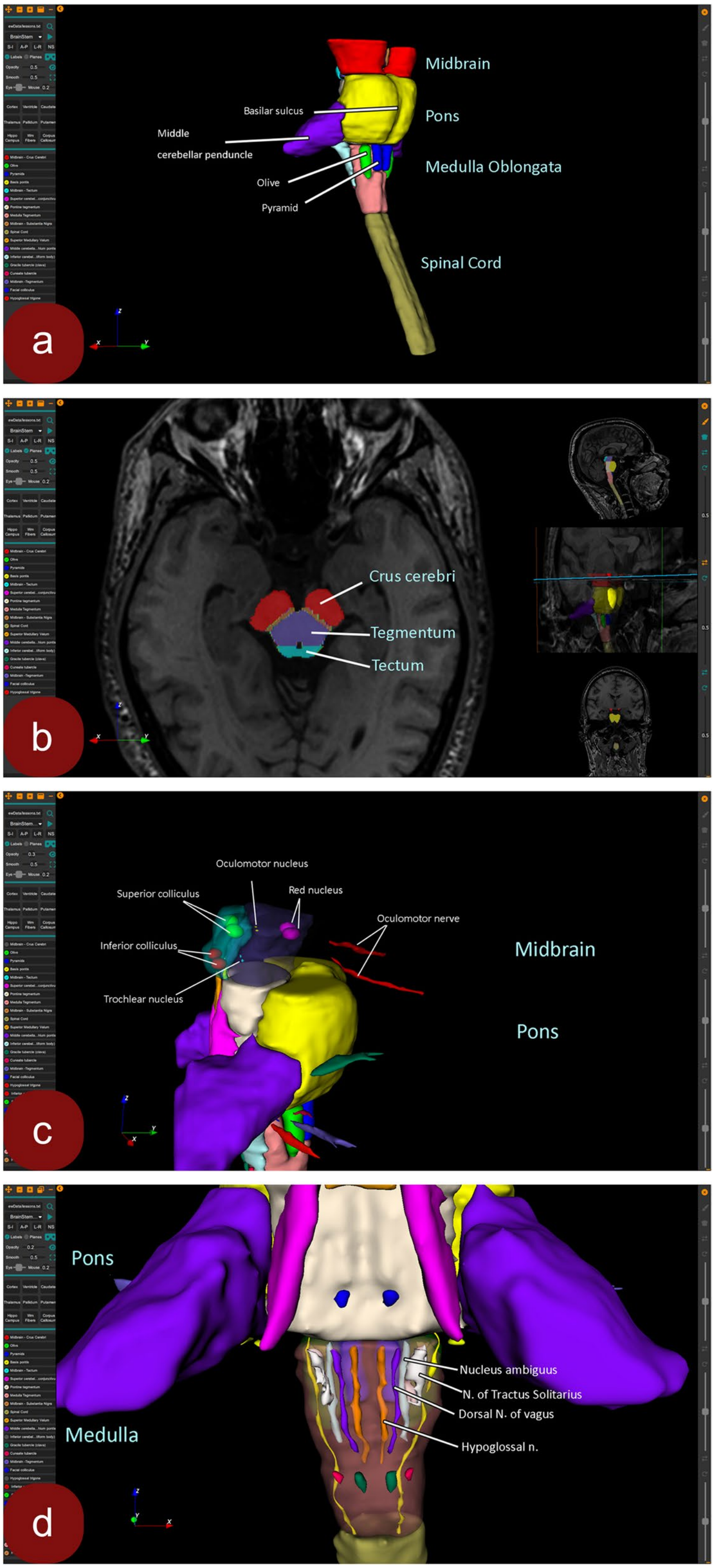

Fig. 3 (See legend on previous page.)

Indian examinations). The impact on cognitive load while teaching with *AnaVu* is also unknown. Hence the authors explored the broad research question "Is teaching using *AnaVu* helpful in Anatomy learning in Indian medical education".

Research questions

Specifically, the research questions we explored were:

1. Is using *AnaVu* tool better than traditional teaching methods?
2. If so, does stereoscopic projection have an advantage over monoscopic projection?
3. Within four general domains of anatomy (vide infra – Methods), (e.g., basic recall, analytical learning, radiologic anatomy, and diagram-based questions) are these specific domains influenced by teaching with *AnaVu*?
4. How do the students' perceived cognitive loads vary between the three types (stereoscopic, monoscopic, and traditional) teaching?
5. If monoscopic and stereoscopic models were presented to a student, what would the student prefer?

Methods

A three-limb randomized controlled trial was designed and submitted before the Institutional Review Board and Human Ethics Committee of Government Medical College, Thiruvananthapuram (GMCT). The HEC gave a letter dated 02.07.2019 stating that the study is exempted from review, based on the 2017 ICMR guidelines, as it is a study assessing educational techniques in medical students.

Sample

The 2022 cohort comprising of 250 first-year MBBS students of GMCT was informed about the study. We follow a dissection-based regional anatomy course. The students had completed upper limb, lower limb, thorax and had started head and neck anatomy. They had not yet started the neuroanatomy module and could be considered as new to the neuroanatomy topic. An information handout and a consent form were provided, which they had to sign and return if they consented (Supplementary material 1). From those who consented (224 out of 250), 152 students were selected using simple random sampling. The random number tables were generated by Microsoft Excel for the study. The students age and sex were collected using a Google Form distributed to the study participants. The 152 students were later randomized to three groups for the intervention (See Study procedure below).

Topic and justification

The basic anatomy of the brainstem and the main cranial nerve nuclei were taken as the lesson for the study. The rationale for selecting this topic was the following:

It is a relatively smaller area in the brain but is highly clinically relevant. It is also difficult to understand spatially. There are numerous complicated anatomical terms (tectum, tegmentum, mesencephalic nucleus of trigeminal, facial colliculus) in the brainstem, which adds to the difficulty in recalling. The brainstem is classically taught by studying 2D sections of different levels (e.g., upper midbrain, lower pons, upper medulla). Correlating 2D sections with 3D mental images is quite spatially complex, especially for the internal architecture of the brainstem [3]. Correlation of the 2D sectional image with the 3D spatial model is needed to understand the radiological anatomy and interpret lesions in a clinical setting.

Pre-test and post-test

The pre-intervention (Pre-Test) and Post-intervention test (Post-Test) (See Supplementary material 2) were applied before and after the intervention, respectively. The duration of each test was 20 min. The questionnaire was designed to incorporate questions from different areas taught in the lecture, dissection and intervention sessions. The maximum possible score was fixed as 35.

The pre-test and post-test had 4 domains (see Supplementary material 2 for questions).

1. Basic recall questions (qn no. 1 – 4) – Maximum possible score was 11
2. Analytical questions (qn no. 5 – 7)—Maximum possible score was 11
3. Radiologic anatomy-based questions (qn no. 8 – 11)—Maximum possible score was 8
4. Diagram-based questions (qn. No. 12 – 13)—Maximum possible score was 5

Pre-test and post-test questionnaire were designed by the authors (divided to four teams for each domain) and face validated by the senior professors of the Anatomy department. This was done similar to the approach done by other studies evaluating 3D teaching tools in anatomy education [40]. The questions had explored various levels of Bloom's taxonomy of inquiry. A modified Bloom's taxonomy category was mapped by two authors and a consensus was calculated (similar to Palmer et al. [41]) for these four domains and are presented in Fig. 4. As the students were naive considering the neuroanatomy topic being taught, the pre-test and post-test were designed to be the same.

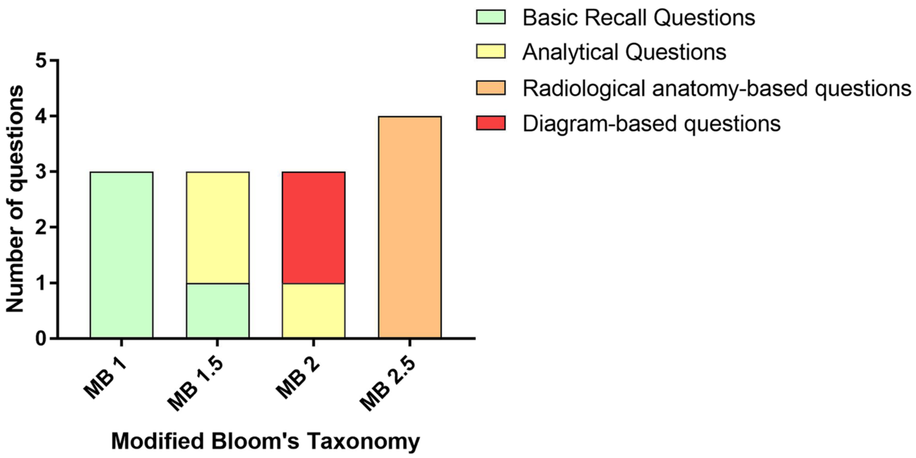

Fig. 4 Number of questions of various domains (indicated as colors) at different Modified Bloom's (MB) Taxonomy (consensus between two authors)

Perceived cognitive load assessment tool

The perceived cognitive loads by students was assessed based on a tool by Leppink et al. [34] with a minor adaptation to suit the current teaching experiment. This minor adaptation was done as the original tool was designed for statistics education and is permitted [34]. The tool consisted of 10 questions (see Supplementary material 3), with the first three questions (il1, il2 and il3) indicating the IL; the next three questions (el1, el2 and el3) indicating the EL; and questions 7–10 (gl1, gl2, gl3 and gl4) indicating the GL. They were given this instruction in the material "Please respond to each of the questions on the following scale (0 meaning not at all the case and 10 meaning completely the case)", as indicated in source [34].

Subjective feedback questionnaire

A subjective feedback questionnaire that contained 12 specific questions and a section to give open comments was used. For the 12 specific questions, a five-point Likert scale was used to obtain student ratings, with 1 indicating "strongly disagree" and 5 indicating "strongly agree". The first five questions were adapted from the tool used by Codd and Choudhury [40], which was to assess a virtual reality tool for forearm anatomy compared to the traditional method. The questions asked whether it was enjoyable (Q1), relevant (Q2), useful (Q3), well presented (Q4) and whether they would like to see a similar resource in future (Q5). It was aimed at understanding the general appreciation of the tool. The next five questions were adapted from the tool used by Maresky et al. [42], to assess a virtual reality tool for cardiac anatomy. It tried to explore whether it reinforced their anatomy knowledge (Q6), enhanced their anatomy integration skills (Q7), improved visuo-spatial skills (Q8), assisted in appreciating size differences (Q9) and anatomical relationships (Q10) of different structures. The last two questions were negatively worded so as to break up a response pattern in which participants typically answer positively or negatively to all items in the survey questionnaire. They were asked whether the tool distracted their learning (Q11) or whether it was confusing (Q12). In addition to these specific questions, there was also an option to provide open comments by asking them to write "Any specific comments about the Demonstration". The questionnaire is shown in Supplementary material 4.

Study procedure

The educational session lasted for 2 days (see Fig. 5 for the underlined parts in the text below).

- *On Day 1*, the students were given a briefing and then a 20-min pre-test, which was then followed by an introductory lecture on the brainstem, for 40-min duration. The lecture was a usual didactic lecture and introduced the basics of brainstem anatomy (the parts – medulla, pons and midbrain and their subdivisions) including their relations. The parts and terminologies were introduced. The cranial nerve nuclei present withing the brainstem were also taught in the lecture. All were taught using PowerPoint projected 2D slides. The slides contained text and gross anatomy whole specimen images, section images, diagrams and MRI images (axial and sagittal cuts of brainstem region). They were then given a demonstration of dissection specimen of the brainstem, for 20 min using a doc-

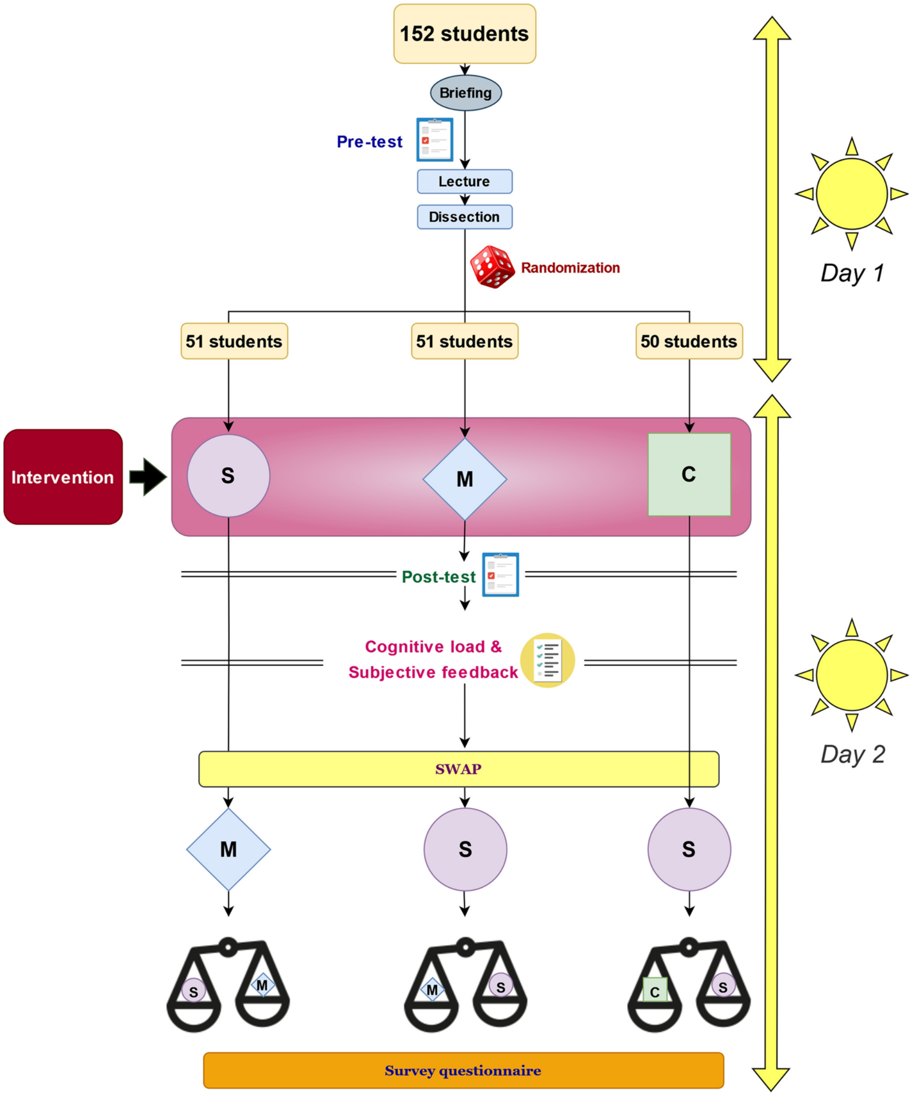

Fig. 5 Flow diagram depicting the sequence of the current study protocol. S, stereoscopy; M, monoscopy; C, control. Weighing scales at the bottom indicates that those students were allowed to compare the S to M (limb 1); M to S (limb 2); and C to S (limb 3) and tell what they preferred in the survey questionnaire that was given

ument camera. The surface features that is seen on the medulla, pons and midbrain both from ventral and dorsal aspects were demonstrated to students. Visibility was ensured using a document camera, which is routinely used at GMCT for demonstration of smaller structures in dissection to a larger group. Both the lecture and the dissection demonstration were conducted by a single teacher.

- Based on the first intervention they would receive the next day, the student groups were named S, M and C, representing Stereoscopy (S), Monoscopy (M) and Control (C), respectively. The 152 students were randomized into the three groups by allocating the first 51 of the random numbers (generated earlier for selecting the sample) to S, the next 51 of the random numbers to M and the next 50 to C (see Fig. 5).
- *On Day 2*, the S, M and C groups assembled at three separate venues (See Hybrid Fig. 6). The teaching sessions were instructor led demonstrations.
- Certain steps were taken for the intervention sessions to ensure uniformity in the content being taught in the three groups.

The Interventions

Stereoscopy

S was given a demonstration of the brainstem lesson module in *AnaVu (20 minutes)* in stereoscopic projection mode. Teacher and the students had to wear linearly polarized 3D glasses (goggles) for this session. This was conducted at SCTIMST. The room was dimly lit for clearer visualization.

Monoscopy

M was shown a demonstration of the brainstem lesson module in *AnaVu (20 minutes)* in monoscopic projection mode. Teacher and the students did not wear any specialized eyewear for this session. This session was conducted at the Anatomy Lecture Theatre, GMCT

Control

C was given a demonstration using white/black board-drawn diagrams (20 minutes). The diagrams were drawn on the boards beforehand by one of the authors so as to utilize the time available (20 minutes) effectively for teaching. This was conducted at the Histology Laboratory, GMCT.

Fig. 6 Hybrid table showing different interventions. The second column of the panel contains the photographs -**a**,**b** and **c** from sessions that were held for the three groups – S,M and C respectively

Table 1 Demographic values of stereo, Mono and control group

Test	Stereo	Mono	Control	*p* -value; Statistical Test	Total
n	51	51	50		152
Age: Mean (± SD)	20 y (± 2.2)	20.1 y (± 1.03)	20.24 (± 1.39)	$p = 0.76$; ANOVA test	20.11 years (± 1.61 y)
Male: Female ratio (M:F)	18: 33	19: 32	23: 27	$p = 0.504$; Chi-square (χ^2) test	60:92
First quarterly examination scores (out of 100)	47.83(± 13.47)	46.62(± 14.53)	48.04(± 10.67)	$p = 0.839$; ANOVA test	47.49(± 12.95)

    - A teaching script was prepared earlier to make the teaching content as similar as possible. The content delivery was validated for consistency by six senior students, two in each venue.
    - All the intervention sessions (S,M and C) were conducted by another teacher, different from the teacher who took the lecture and dissection demonstration
    - The time of each session (20 min) was monitored and strictly adhered to.

- After this, the students were given a post-test and a perceived cognitive load assessment questionnaire (Supplementary material 3) and a subjective feedback form (Supplementary material 4).
- A 15-min break was given.
- After this, the students were swapped, similar to the pseudo-cross over mentioned in Cui et al. (2017) [43]. The students had to change the venues to attend the respective sessions. The S group moved to the venue where a mono demonstration was given, the M group moved to stereo demonstration, and the C group moved to a stereo demonstration (see bottom of Fig. 4). The timings were coordinated by the senior students. Participant students were informed that this was essentially a "replay" of the previous session they had had, but using a different teaching modality (M given Stereo, S given Mono and C given Stereo). They were informed that this was done to allow a comparison of the two methods and know their preference. After the session, they were given a survey questionnaire for knowing their preference (e.g., the SM swap group was given Supplementary material 5).
- Students were thanked for participation, and light refreshments were provided.

Analysis

Demographical details were analysed. To know whether there was a statistically significant different in age and sex categories among the three groups an ANOVA test and a Chi-square (χ^2) test was performed. Pre-test and post-test were evaluated by the authors following an answer key, prepared by themselves and face validated by the senior professors of the Anatomy department. The quantitative data were entered in Microsoft Excel for Windows and imported to SPSS Statistical package, version 25.0 for Windows (IBM Corp., Armonk, NY) for analysis. Since the three modes of demonstrations needed to be compared for its effectiveness, the difference (increase or decrease) [Post-test (minus) Pre-test scores] of each person was calculated. Analysis of Variance test (ANOVA) was performed to detect any statistically significant difference in mean scores among groups. Statistical limit was fixed as $p < 0.05$. If a significant difference was found on the ANOVA test, post hoc tests with Bonferroni corrections for multiple comparisons were performed to identify the pairs that had a statistically significant difference. Cohen's d was calculated ($M_1\text{-}M_2/SD_{pooled}$) to determine the effect size to measure the quantum of the difference between a pair (In this formula, M_1 and M_2 stands for Mean of each group in the pair and the SD_{pooled} is the combined SD of the pair). The effect sizes were interpreted as small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$), as per previous reports [44].

Cognitive loads (IL, EL and GL) of the three groups were also compared using ANOVA test. For analysis of the subjective feedback questionnaire (12 items), the mean and standard deviation of the response of each item were calculated and compared among the three groups using ANOVA test. Graphs were generated using SPSS Statistical package, version 25.0 for Windows (IBM Corp., Armonk, NY) and draw.io (https://app.diagrams.net/) webpage.

Results

Quantitative analysis

Demographics

The mean age (± SD), male to female ratio and the first quarterly examination scores of the whole sample of students are shown in Table 1.

The age of the groups was found to be statistically similar among the groups ($p = 0.76$; ANOVA test); and

Table 2 Table showing total scores secured in Pre/post test

Test	Stereo Mean (± SD) (Max. possible score for pre/post test – 35)	Mono Mean (± SD) (Max. possible score for pre/post test – 35)	Control Mean (± SD) (Max. possible score for pre/post test – 35)	*p* value (Test)
Total Pre-test score	1 (± 1.12)	0.94 (± 0.93)	1 (± 1.05)	0.947 (ANOVA)
Total Post-test score	16.98 (± 7.18)	15.22 (± 7.62)	14.47 (± 7.84)	0.233 (ANOVA)
(Post-Test score) – (Pre-Test score)	15.98 (± 7.11)	14.28 (± 7.54)	13.47 (± 7.63)	0.226 (ANOVA)
p value (Test)	< 0.001* (Paired t test)	< 0.001* (Paired t test)	< 0.001* (Paired t test)	

* indicates statistical significance ($p < 0.05$)

Table 3 Table showing domain-wise analysis of post-test – pre-test (difference) scores

Test	Stereo Mean (± SD)	Mono Mean (± SD)	Control Mean (± SD)	p value (Test)	Bonferroni corrections/ Post-hoc analysis *p* value		(Cohen's *d*) Effect size
Basic Recall based questions (Recall)	5.35 (± 2.83)	3.97 (± 2.83)	3.32 (± 2.33)	0.001* (ANOVA)	S,M	0.03*	0.488
					S,C	0.001*	0.783
Analytical based questions (Anal)	3.28 (± 2.06)	3.44 (± 2.45)	3.74 (± 3.05)	0.661 (ANOVA)	N/A		N/A
Radiology based questions (Rad)	4.68 (± 1.69)	4.09 (± 2.09)	3.14 (± 2.02)	< 0.001* (ANOVA)	S,C	< 0.001*	0.827
					M,C	0.046*	0.462
Diagram based questions (Diag)	2.78 (± 1.63)	2.78 (± 1.62)	3.27 (± 1.50)	0.196 (ANOVA)	N/A		

* indicates statistical significance ($p < 0.05$)

sex were also similar among the groups ($p = 0.504$; Chi-square (χ^2) test). The first quarterly examination out of 100 also did not show statistically significant difference ($p = 0.839$; ANOVA test) among three groups. Hence the three groups were demographically comparable.

Test scores

The maximum possible score of the pre-test was 35. The total pre-test scores did not differ among groups (S, M and C), as shown by statistical analysis (Table 2, Row 1; p value = 0.947; ANOVA). The maximum possible score of the post-test was also 35. All the three modalities of teaching S, M and C showed statistically significant increase in scores from pretest to post test (Table 2, Row 1, p values < 0.001; Paired t test). The total post-test scores did not differ among groups, as shown by statistical analysis (Table 2, Row 2; $p = 0.233$, ANOVA). The difference between the total post-test and pre-test scores, which indicates the increase/decrease in the students' understanding, also failed to show a statistically significant difference among groups (Table 2, Row 3; $p = 0.226$, ANOVA).

Domain-specific analysis indicated statistically significant difference among groups in the basic recall domain (Table 3; Row 1; p value = 0.001; ANOVA). The difference was statistically significant between the Stereo and Mono pair [S. $\text{Recall}_{\text{Mean}} = 5.35$ (± 2.83) vs M. $\text{Recall}_{\text{Mean}} = 3.97$ (± 2.83); p value = 0.03; post hoc tests, Bonferroni corrections applied] as well as between the Stereo and Control group pair [S. $\text{Recall}_{\text{Mean}} = 5.35$ (± 2.83) vs C. $\text{Recall}_{\text{Mean}} = 3.32$ (± 2.33); p value = 0.001; post hoc tests, Bonferroni corrections applied].

A statistically significant difference was also noted in radiology-based questions in the test (Table 3; Row 3: p value < 0.001; ANOVA). The difference was statistically significant between the Stereo and Control pair [S. $\text{Rad}_{\text{Mean}} = 4.68$ (± 1.69) vs C. $\text{Rad}_{\text{Mean}} = 3.14$ (± 2.02); p value < 0.001; post hoc tests, Bonferroni corrections applied] and between the Mono and Control pair [M. $\text{Rad}_{\text{Mean}} = 4.09$ (± 2.09) vs C. $\text{Rad}_{\text{Mean}} = 3.14$ (± 2.02); p value = 0.046; post hoc tests, Bonferroni corrections applied].

There was no statistically significant difference in the scores of analytical questions or diagram-based questions (Table 3; Rows 2 and 4).

Cognitive loads

The perceived cognitive loads by the students showed a statistically significant difference among the groups for germane cognitive load (GL) (Table 4, Row 3; p value = 0.001; ANOVA). The difference was statistically significant between the stereo and control pair [S.

Table 4 Table showing perceived cognitive load domains of the three groups

Cognitive load domain	Stereo Mean (±SD)	Mono Mean (±SD)	Control Mean (±SD)	*p* value (ANOVA)	Bonferroni corrections/ Post-hoc analysis		(Cohen's *d*) Effect size
Intrinsic Load (IL)	16.71 (±6.13)	16.57 (±7.72)	17.98 (±5.40)	0.487			
Extrinsic Load (EL)	2.37 (±3.97)	1.39 (±2.66)	2.80 (±3.67)	0.122			
Germane Load (GL)	33.28 (±5.35)	32.80 (±7.91)	28.18 (±8.17)	0.001*	S,C	0.002*	0.739
					M,C	0.005*	0.575

* indicates statistical significance

GL $_{\text{Mean}}=33.28$ (±5.35) vs C. GL $_{\text{Mean}}=28.18$ (±8.17); *p* value = 0.002; post hoc tests, Bonferroni corrections applied] and mono and control pair [M. GL $_{\text{Mean}}=32.80$ (±7.91) vs C. GL $_{\text{Mean}}=28.18$ (±8.17); *p* value = 0.005; post hoc tests, Bonferroni corrections applied]. There was no statistically significant difference among groups in intrinsic (IL) and extrinsic loads (EL).

Subjective feedbacks questionnaire

The subjective feedback questionnaire mean responses on the 5-point Likert scale are shown in Fig. 7 (error bars indicate standard deviation). S and M showed a higher mean response in the first 10 statements. The ones that showed statistically significant differences among the groups (as per ANOVA) are shown with a red star. Two red stars beside the comments (see Fig. 7; statement numbers 1, 3, 6, 7, 8, 9 and 10) indicate statistically significant differences for S when compared to C and for M when compared to C. A single star indicates a statistically significant difference for S when compared to C (see Fig. 7; Qn 5).

In the stereo-mono-swapped pooled cohorts (total 102; SM: 51 participants and MS: 51 participants), when they were asked about which mode would be preferred, through the survey questionnaire, 79/102 preferred S, 13/102 preferred M and 6/102 preferred both.

Discussion

The current study sheds light on the pedagogical advantages of a newer 'homegrown' developed technology for visualizing anatomy in Indian anatomy education scenario and provides insights into the merits and demerits of the technology through the comments of the students. The teacher's feedbacks on using *AnaVu* has been recently published (64) and it indicated general appreciation and advantages for teaching spatial anatomy but also some critical disadvantages for teachers while using the S mode due to lack of interaction with students in a darkened room, eye strain and need for the user interface training for teachers. In time, resource and technology constrained settings, the specific advantage and disadvantage of a new tool, such as *AnaVu*, should be revealed and convincing for teachers and students to implement such a technology for better neuroanatomy learning [2].

Here, the pretest scores (Table 2, Row 1) and the demographic data (Table 1) of the S, M and C groups indicate comparability of the three groups before the intervention. Although the total test scores and difference of total post-test minus pre-test scores were not significantly different for the three groups (Table 2, rows 2 and 3), domain-wise analysis showed significant improvement for the S group compared to the M and C groups in the basic recall test (Table 3, Row 1). Recalling terms, orientations, relations, etc., in anatomy is a complicated process. In a study exploring factors leading to impaired learning of neuroanatomy, the participants mentioned 'memorization of neuroanatomical terminologies' to be and important intrinsic contributing factors [1]. Optimal instructional techniques can create a favorable cognitive environment that enhances their ability to recall and has been indicated in several contexts of anatomical learning environments [30, 45]. On understanding how human cognitive system works during learning with multimedia (Mayer's cognitive model [46]), a clear visualization with cues to direct the learner's attention to a specific structure along with clear explanation can moderate cognitive loads favoring active and effective learning [30]. This may have influenced the result of better basic recall scores in the S (compared to M and C), due to better visualization.

Now why can the effect be more in S compared to M? The authors propose that stereopsis may play a role in the clarity of depth perceptions which thus influence the better basic recall. Earlier, it was mentioned that stereopsis in the *personal space (up to a 2 m radius around a person)*, as during performing dissection, observing prosections, manipulating a manikin or a physical anatomical model, provides a substantial advantage in perceiving depth and spatial information [21]. Providing stereopsis in the *action space (2 m-30 m)*, as in the case of stereo display (S mode in our experiment), may create such an effect for the large group of students tested here. The statistically significant difference of S. Recall$_{\text{Mean}}$ compared to C. Recall$_{\text{Mean}}$ with a large effect size (Cohen's $d=0.783$) indicates that stereopsis in the action space created by S

Fig. 7 Graphical representation of the mean values of the 5-point Likert scale responses to statements as part of subjective feedback. Bars—Purple for Stereo, Blue for Mono, and Green for Control—show the mean values. Error bars are also shown (± SD). The statements with *Only S had statistically significant difference from C; **Both S and M had statistically significant difference

mode display, may have been effective in providing critical details of depth and spatial information, with clear attentional cues. Earlier studies have shown how spatial and attentional cues in 3D dynamic visualizations can make anatomy learning better [47]. This may have augmented their learning and thus their ability to recall. Students' opinions in their subjective feedback about understanding size differences and relations were statistically higher for S and M compared to C (see Fig. 7, statements 9 and 10). This reinforces the idea of role of visualizations in anatomy learning success and the need for modern visualization methods.

This effect of the S mode was better even when compared with the M mode, as indicated by S. $\text{Recall}_{\text{Mean}}$ compared to M. $\text{Recall}_{\text{Mean}}$ with a moderate effect size (Cohen's $d = 0.488$). This may indicate that although there are depth cues in the M mode (perspective projection, shadings, occlusion, motion perspective, familiar size), as discussed earlier [20, 29], they may not be adequate to create sufficient depth perception to influence anatomical learning, when compared to how it was in S. Depth cues were utilized extensively in the design of the interactive 3D viewport of *AnaVu*. As stereopsis is a significant part of visual perception that aids in understanding the spatial disposition of the world around us [20], this finding may indicate the value of stereopsis in anatomical learning and adding to the data indicating superiority of stereoscopic visual display in anatomy education [48, 49] especially compared to monoscopy.

Another domain that showed a statistically significant advantage was for learning radiological anatomy. As familiarizing anatomy students with radiological anatomy helps them integrate different subjects [17], makes anatomy learning effective [18] and improves spatial reasoning skills [19], the advantage of *AnaVu* to teach radiological anatomy is twofold. The current CBME curriculum in India envisages vertical integration across basic and clinical disciplines. It also encourages early clinical exposure to first-year medical students [50]. In this context, teaching anatomy from stereoscopic models generated from T1 weighted MRI images and displaying the anatomy and the radiological source images in a 3D mode correlatable to the 2D MRI images can be an effective technological solution for bridging the gap between radiological anatomy and gross anatomy. Anatomy and radiology are usually considered complementing disciplines that have an enormous scope for integration [17]. Hence, this tool is a promising approach for radiological anatomy teaching. Considering the fact that S. Rad_{Mean} vs C. Rad_{Mean} had a high effect size (Cohen's $d = 0.827$; Table 1, Row 3) and M. Rad_{Mean} vs C. Rad_{Mean} had a moderate effect size (Cohen's $d = 0.462$; Table 1, Row 3), using this tool in the S mode or in the M mode is effective for radiological anatomy teaching. The higher effect size seen here of S vs C compared to M vs C may also be due to the better effect of stereopsis in integrating spatial concepts making radiological anatomy interpretation better. The authors propose that a hidden common factor here in basic recall (due to the effect on cognitive load due to better spatial cues) and radiological image interpretation here is the underlying higher spatial learning in stereoscopy. Studies have shown that spatial abilities and better spatial learning influence anatomy learning success [51, 52]. Students in their subjective feedback also mention that this mode of learning helped them improve their visuospatial skills (Fig. 7; Statement 8).

Students' perceived cognitive loads had a statistically significant difference in the GL with high effect size (Cohen's $d = 0.739$) for S vs C and a moderate effect size (Cohen's $d = 0.575$) for M vs C. The germane or generative load reflects the ability of the student to make sense of the structures shown, organize mental concepts and integrate new understanding with prior knowledge [30, 53]. The higher cognitive load may indicate that the students could add up on what was learned on the previous days lecture and dissection demonstrations effectively with ease when taught with *AnaVu* compared to the board drawn diagrams. This is corroborated by the positive comments seen in the students' subjective feedback questionnaire responses when they say how it helped them to integrate with previous knowledge on brainstem anatomy and how it helped in Anatomy integration skills (Fig. 7 Statements 6 and 7). Their perception as it was enjoyable and useful (see Fig. 7, Statements 1 and 3) may also indicate their better GL. Students also mentioned that they appreciate similar teaching methods in the future (Fig. 7; Statement 5).

Though some of the well-known drawbacks of S mode are low ambient light requirements causing difficulty in interaction with teachers [39], requirement of wearing eye goggles (which can cause discomfort as it is often bulky [29]), eye strain complaints and difficulty in focusing and concentrating [54], there seems to be a general preference for the students in the survey questionnaire response in the present study. When they were asked about their preference after they were exposed to both SM/MS out of 102, 79 preferred S. The rest of the students [13] who showed preference of M and 6 who showed preference of both may have felt M to be as good as S, or could have felt the disadvantages of S to be more distracting.

Limitations of the study

The number of questions asked in the pre-test and post-test were limited. This was due to the limitation of available time to conduct the whole experiment. However, they were face validated. This may have affected the statistical power of the study.

A time for students to familiarize with stereoscopy by directly manipulating the tool may have been needed to be adapted to the stereoscopic environment.

During C intervention, as it was black/white board diagrams, control group did not learn through MRI images, while as *AnaVu* had radiological sectional images inside the tool, S and M learned using MRI images. But as we had to compare traditional and a modern tool, this was unavoidable. However, to avoid unfair exclusion of the control group from sectional MRI images, few MRI images (sagittal and axial) were used during the common brainstem lecture. Also as the medical students were in the midst of the regional anatomy course, with limbs, thorax and head and neck anatomy partially over, they were exposed to basic radiology in these segments.

The assessment of spatial ability of the students was avoided, but if done would have added an interesting angle to the study as spatial ability of students is a proven factor in spatial learning. This can be a further direction of the study.

Conclusions

Technological solutions for educational effectiveness are an area where Indian medical education is stepping into and is highly relevant as the NMC has commenced the futuristic CBME curriculum. As the newer e-learning techniques using hand-held devices, web-based platforms and computer-assisted learning modalities are increasingly being relied on [1], the understanding of the relevance of stereopsis (by means of stereo display) in this study will help in developing e-learning and self-learning strategies in anatomical education. The enhancement in basic recall and utility for radiology education using the low-cost *AnaVu* stereo display may encourage anatomy educationalists to actively seek methods for making students learn anatomy through visualization. The specific disadvantages of the stereo display and the areas where a mono display is effective along with the students' subjective perspectives can help teachers choose the best visualization method in an informed manner.

Abbreviations

S	Stereoscopy
M	Monoscopy
C	Control
3D	Three-dimensional
2D	Two-dimensional
MRI	Magentic Resonance Imaging
IL	Intrinsic Load
EL	Extrinsic Load
GL	Germane Load
CBME	Competency-Based Medical Education
NMC	National Medical Council (of India)
ANOVA	Analysis of variance
SD	Standard Deviation

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-05910-4.

Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

Supplementary Material 4.

Supplementary Material 5.

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Authors' contributions

DGY: Segmentation of the model, conceptualized and developed the idea, designed the study, performed the anatomy instruction, analyzed and interpreted the data and drafted the manuscript.AMO: Designed the study, performed the anatomy instruction, interpreted the data and played a role in drafting and critically revising the manuscript.ASK, SD, MR, NS, NET, NA: Implementation, collection of data and teaching supportNKR: Statistical data analysis and prepared table and figures BT, JER: MRI image acquisition, Segmentation of the model, visualization requirement specification and feedback on user-interface of the software toolUKG: Conceptualization and organization of the study, statistical data analysisPH: Conceptualisation, design and engineering of *AnaVu* toolTRK: Mentor and advisor who oversaw the study with timely, insightful guidanceCK: MRI image acquisition, Segmentation of the model, visualization requirement specification and feedback on user-interface of the software tool, and supervision of the study.JS: Primary investigator of the project. Visualization of the model, conceptualization, organization, supervision and overseeing the study.

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Availability of data and materials

The datasets generated and analyzed during the course of this study are not publicly available due to concerns about the privacy of participants but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Human Ethics Committee of Government Medical College, Thiruvananthapuram (GMCT). The HEC gave a letter dated 02.07.2019 stating that the study is exempted from review based on the 2017 ICMR guidelines, as it is a study assessing educational techniques in medical students. Written informed consent was obtained from the participants by providing an information handout and consent form. The participants were informed about the purpose, nature and procedure of the study as well as the fact that their participation was voluntary. They were assured confidentiality and that the data would be used only for research purposes. They were also informed that when the data will be published their personal details will be kept confidential. A portion of this study, focusing on the development of the tool, was presented at the annual conference of the Anatomical Society of India (Kerala State Chapter) held at Government Medical College, Kozhikode, in May 2023. A part of the results of this study was presented for oral/podium presentation at the Asia Pacific International Congress of Anatomy—Australian and New Zealand Association of Clinical Anatomists joint conference (ANZACA – APICA 2023), held at the University of Otago, Dunedin, New Zealand, in November – December 2023.

Consent for publication

Informed consent was obtained from all subjects for publication of identifying information/images in an online open-access publication.

Competing interests

The authors declare no competing interests.

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