Derakhshan *et al. BMC Medical Education* (2025) 25:485
https://doi.org/10.1186/s12909-025-07058-1

BMC Medical Education

RESEARCH

Open Access

Production and educational value of anatomical megamoulages

Homayoon Bana Derakhshan[1], Hamed Shoorei[2,3,4*], Gholamreza Hassanzadeh[5*], Mohammad Reza Mansoorian[6], Jalil Moshari[7], Moosa Sajjadi[8], Mehrnaz Ghaffari[9], Sajed Khaledi[10] and Jamal Majidpoor[5,11*]

Abstract

Background Anatomy is a crucial aspect of biological sciences and medical education, playing a pivotal role in various clinical practices. To enhance the existing curriculum and improve students' spatial understanding of anatomy, educators have explored the use of moulages. In a groundbreaking study conducted in 2022–2023, the effectiveness of *megamoulages* in enhancing the comprehensive understanding of anatomy among medical students at Gonabad and Kurdistan University of Medical Sciences was thoroughly assessed. The produced *megamoulages* are not simply larger than conventional moulages; rather, they present anatomical details more clearly, including maximum anatomical points, structures, and neuro-vascular relationships as described in reference books and articles, which were not adequately represented in previous models, and they are also hand-painted.

Methods The production of *megamoulages* involved a comprehensive 20-month sequential process. Initially, a needs assessment questionnaire was administered to medical students, residents, medical faculty surgeons, and anatomists to evaluate the project's feasibility and significance. Results revealed that the majority of respondents (88%) believed the production of *megamoulages* would facilitate anatomy education. Anatomical models were strategically selected based on their complexity and the unavailability of similar models from foreign companies. *Megamoulages* (two groups of *megamoulages*: the first includes unique models, such as a sectional *megamoulage* of the brainstem that displays all structures in detail, while the second group (cerebellum and mandible) as improved quality models, which are similar to existing ones) were designed using 3D software, printed in sections, and assembled with magnets. The completed moulages were subjected to thorough evaluations following Kirkpatrick's model, which included methods such as smile sheets and scientific tests administered to randomly divided third-semester medical students in the mentioned universities.

Results In both universities, student satisfaction with the use of *megamoulages* was significantly higher compared to conventional moulages ($P<0.05$). Additionally, in a written test, students who utilized *megamoulages* achieved an average score that was about 2.73 points higher than those who used conventional moulages ($P<0.05$).

*Correspondence:
Hamed Shoorei
h.shoorei@gmail.com
Gholamreza Hassanzadeh
hassanzadeh@tums.ac.ir
Jamal Majidpoor
jmajidpoor@gmail.com
Full list of author information is available at the end of the article

Conclusion The implementation of *megamoulages* significantly enhanced the scores of anatomy learners. This study underscores the importance of innovative teaching tools, such as *megamoulages*, in improving anatomical education and increasing student satisfaction.

Keywords *Megamoulages*, Anatomy, Learning, Anatomy education, Medical students

Introduction

Human anatomy explores the structures of the human body through macro anatomy, microanatomy, and evolutionary anatomy [1]. Anatomy education holds significant importance as an integral part of medical studies worldwide. In Iran, anatomy courses, including Gross Anatomy, Histology, and Embryology, are mandatory at the beginning of medical education and form a major component of basic medical science courses [2]. Clinical experts in the field acknowledge that a strong foundation in anatomy is crucial for safe and effective clinical practice. Therefore, adopting a practical and clinical approach to teaching anatomy is necessary to minimize medical errors among students [3]. Moreover, students' awareness of the significance and clinical applications of anatomy plays a vital role in their skill development. Anatomy is indispensable not only for general medical courses but also for surgical specialties and individuals involved in aggressive treatment and diagnostic procedures [3].

Anatomy training sets itself apart from other basic science courses such as physiology and biochemistry due to its distinct requirements for teaching and learning tools. Various approaches to teaching anatomy involve the use of tools such as cadavers, moulage, human body atlases, training videos, and slides [4].

The use of wax models, or moulages, in anatomy education, has a centuries-long history. Allessandra Giliani, an anatomist in the fourteenth century, played a pivotal role in introducing this artistic and visually captivating approach [5]. Nowadays, moulage involves creating lifelike representations of anatomical structures through realistic simulations and models [6]. Its significance lies in its contribution to anatomy learning, providing realistic representations and fostering hands-on experiences. Moulage also facilitates clinical skills training, promotes problem-solving and critical thinking, encourages teamwork and communication, and aids emotional and psychological preparation [6, 7]. Incorporating moulage into anatomy education helps students develop a comprehensive skill set for their medical careers. Nonetheless, current moulages present several challenges, including the difficulty in clearly representing intricate structures, inaccuracies in production, misalignment with actual organs, and the inability to accurately depict adjacent structures [8].

Together, for the first time in anatomy education courses, we have explored the potential advantages of incorporating larger-sized moulages, *megamoulages*, in anatomy education, contrasting them with the more common use of smaller-sized models. *Megamoulage*, a term that combines "moulage" with "mega," refers to the use of large-scale moulage techniques in anatomy education. It involves creating expansive and immersive moulage simulations that go beyond individual models or structures. *Megamoulage* offers students a three-dimensional and immersive learning environment, where they can gain a contextual understanding of anatomy. Through the creation of large-scale moulage simulations that depict anatomical structures within realistic settings like clinical scenarios or anatomical landscapes, students develop a deeper comprehension of the interrelationships between structures, vessels, and nerves. This comprehensive learning experience is facilitated by the incorporation of multiple senses, including touch and sight which enhance the realism of educational simulations [9, 10]. Additionally, the collaborative nature of *megamoulages* allows medical students to work together, fostering effective communication, and teamwork skills. These simulated interactions mirror the dynamics of real healthcare settings, preparing students for future professional interactions in their respective fields.

This study aims to investigate the impact of *megamoulages*, specifically the brainstem model, on the learning outcomes of 3rd-semester medical students at Gonabad and Kurdistan University of Medical Sciences in Iran. The study will assess how the utilization of *megamoulages* influences the students' understanding and retention of the brainstem anatomy. By conducting this research, the study seeks to contribute to the existing knowledge on the effectiveness of *megamoulages* as an educational tool in the medical field.

Materials and methods

The location of study

The study took place at two institutions, namely Gonabad University of Medical Sciences and Kurdistan University of Medical Sciences in Iran in 2022–2023. Participants were recruited from the pool of 3rd-semester students.

Prior to production of *megamoulages*

The production of *megamoulages* involved a sequential process consisting of several distinct stages. From the conception of ideas to the implementation and production of the moulages, the entire duration spanned approximately 20 months. The initial stage of the project involved assessing its feasibility and importance through a needs assessment questionnaire (Table 1) administered to a diverse group of participants ($n = 4000$), including medical students, residents, faculty surgeons, and anatomists across Iran. This was facilitated through social networks and internal messaging platforms, such as Bale, which allowed participants from various programs to share their opinions. Following the survey, the executive team held consultations with professors from the anatomy department at Gonabad University of Medical Sciences, as well as professors from other universities who taught anatomy courses. Through multiple meetings, they reviewed various teaching tools and methodologies employed in anatomical sciences education.

The production of *megamoulages*

We created two groups of *megamoulages*: the first group includes models with no existing counterparts in the market, such as the sectional *megamoulage* of the brainstem, which displays all structures in both external and internal views with maximum detail, and the inguinal canal *megamoulage*, which shows the layers of the anterior abdominal wall separately. The second group consists of models that have similar counterparts, but those existing models are of poor quality. In all these models, we ensured that the maximum anatomical points, structures, and neurovascular relationships, as referenced in books and articles, were accurately represented—something lacking in previous models. Approval for the production of these selected models was obtained from the project presenters.

Table 1 Assessment form for needs evaluation

Questions		Answers	
1	Is it feasible for all students in the anatomy classrooms to adequately observe the details of the models while professors are conducting their teachings, considering the class sizes?	Yes	No
2	Would the models of the brainstem, cerebellum, spinal cord, inguinal canal, mandible, etc., be more suitable for teaching if they were prepared at a size approximately a hundred times larger and with significantly enhanced and intricate details?	Yes	No
3	Would the utilization of larger-sized models for the brainstem, cerebellum, spinal cord, inguinal canal, and mandible in training result in increased retention and durability of the learned material?	Yes	No
4	Are the details of the brainstem, cerebellum, spinal cord, inguinal canal, and mandible accurately represented in accordance with the information provided by anatomy reference sources?	Yes	No
5	In your opinion, is there a necessity for montages of the brainstem, cerebellum, spinal cord, inguinal canal, and mandible that provide clearer and more detailed representations of their respective structures?	Yes	No
6	Are the current sizes of the models for the brainstem, cerebellum, spinal cord, inguinal canal, and mandible appropriate for teaching and learning about the brainstem effectively?	Yes	No
7	Would the quality of learning improve if theoretical material is taught concurrently with practical sessions?	Yes	No
8	Can the utilization of *megamoulages* potentially result in a decreased reliance on cadavers and reduce the exposure of students and professors to formalin?	Yes	No
9	Would the presence of mockups that feature clearly marked vascular, nerve, visceral, muscle junctions, and bony landmarks potentially contribute to an improvement in learning outcomes?	Yes	No
10	Could the use of larger moulages facilitate the teaching of anatomy or surgery?	Yes	No

During the production stage of *megamoulages*, the following steps were undertaken:

1) Design: The external and internal views of the *megamoulages* were meticulously crafted using 3ds Max and SolidWorks software (USA), with a strong emphasis on detail. The design process for each *megamoulage* spanned approximately three months. For sectional *megamoulages*, individual sections were designed and subsequently printed using a 3D FDM (fused deposition modeling) printer from Vafatoos Company in Iran. For instance, the brainstem *megamoulage* was divided into eight sections, each clearly displaying all relevant anatomical points.

2) Printing: Due to the large size of the *megamoulages* relative to the available 3D printers in Iran, the pieces were divided and printed separately. The design files were converted to G-code using Cura software (USA), the standard format for 3D printers. For printing, Polylactic acid (PLA) filament, a biodegradable thermoplastic, was utilized. PLA transitions from solid to semi-liquid at 60–70 degrees Celsius, with a full melting temperature of 190–200 degrees Celsius. Each layer was printed at a height of 0.2 mm, with a material deposition speed of 40 mm/s. The 3D printer's nozzle, through which the melted filament is extruded, has a diameter that affects both detail and speed; a 0.4 mm nozzle was used for this design. Smaller diameters yield more detailed and accurate designs, while larger diameters increase manufacturing speed but reduce precision.

3) Assembly: After printing each piece, specialized adhesives and chloroform were used to connect the sections. Anatomists executed this step to ensure minimal disruptions to the design. The connected parts were then carefully sealed, sanded, and polished to ensure accuracy and maintain the true anatomical appearance.

4) Magnets: To facilitate easy connection and separation of the moulage sections, magnets were inserted into the anatomical sections.

5) Painting: The external surfaces of the printed sections were first painted with acrylic Vesta paint from Ati Mehr Company in Iran, followed by painting all sections. To stabilize the colors and enhance the overall

appearance of the *megamoulages*, a matte varnish from the same brand was applied as a color fixer. Various brushes from Pars-Art (Iran), including flat, liner, fan, round, and filbert brushes, were used throughout the painting process.

Solving probable problems in *megamoulages*

To improve the quality of the *megamoulages*, a feedback and improvement process was implemented. The completed moulages were showcased in the department's dissection hall for two semesters, allowing students, professors, and visitors to provide valuable critiques. During these interactions, feedback was collected to assess the moulages' strengths, weaknesses, anatomical accuracy, structural integrity, realism, and usability. Constructive criticism and suggestions were shared with the project's executive group and then analyzed to enhance the design, production, and presentation of the *megamoulages*.

Learning process evaluation

To evaluate the learning process of 3rd-semester medical students, Kirkpatrick's model [11–13] was employed. The assessment involved two levels: the first level, known as the reaction level, and the second level, referred to as the learning level. At the reaction level, students' responses were measured using a smile sheet or questionnaire. This sheet aimed to gauge their initial reactions and perceptions of the learning experience. It provided insights into their satisfaction, engagement, and interest in the instructional materials, including *megamoulages* and current moulages. The questions were on a Kirkpatrick's scale with very high (5), high (4), medium (3), low options, (2) and I have no idea (1), meaning they were designed to be assigned a rating of 1 to 5.

For the learning level assessment (second level), a scientific test was administered to measure the students' actual learning outcomes. The students, whose total number was 346, were randomly divided into two groups. One group used *megamoulages* as their learning resource, while the other group used existing moulages.

Statistical analysis

Statistical analysis was performed by T-Test and the post hoc Tukey using SPSS 22 software (USA). Data are presented as mean ± standard deviation (SD). The significance level was rated at $p < 0.05$.

Results

Assessment of the need for *megamoulages*

Based on the data presented in Table 2, the survey results indicate that a significant majority (88%) of the participants expressed the view that incorporating *megamoulages* in anatomy courses may be beneficial for effective teaching and learning.

Figures of some *megamoulages*

Figures 1 and 2, and 3 represent the *megamoulages* of the brainstem, mandibular bone, and cerebellum, respectively. In addition, Table 3 shows the diameter of these mentioned *megamoulages* compared to existing ones.

The Evaluation of brainstem and cerebellum *megamoulages* on the learning process of 3rd semester medical students

Table 4 presents the results of the smile sheet-based assessment, which measured the reaction levels of medical students toward the use of *megamoulages* compared to conventional moulages. The study spanned two consecutive semesters and included students who were randomly assigned to either the control group (taught using conventional moulages) or the intervention group (taught using *megamoulages*). The findings of the study revealed that the level of student satisfaction with the utilization of *megamoulages* was remarkably higher in comparison with conventional moulages. This indicates a positive response from the students towards the use of *megamoulages* as a teaching tool in comparison to traditional moulages. The high satisfaction level suggests that the incorporation of *megamoulages* contributed to an enhanced learning experience for the students involved in the study.

Moreover, Table 5 presents the results of an identical written test conducted to assess the performance of anatomy learners in two groups: one group taught with *megamoulages* and the other group taught with conventional moulages. The average grades of the learners using the made *megamoulages* were found to be about 2.73 points higher than those of the group taught with conventional moulages.

Discussion

The course on basic science in medical education holds great importance. It serves as the initial stepping stone towards clinical practice, as a seamless connection between basic sciences and clinical applications is crucial for effective medical education. Within the realm of basic science courses, anatomy holds a fundamental position in medical education, with students typically encountering it during their early years of study. Despite the implementation of changes in the curriculum of anatomy courses across several universities, the predominant methods of teaching anatomy continue to revolve around lectures and hands-on practical training, including cadaver dissection and the utilization of anatomical moulages. The objective of this study was to evaluate the importance of incorporating *Megamoulages* as a novel approach for teaching anatomy to third-semester medical students at Gonabad and Kurdistan University of Medical Sciences.

Table 2 Medical students', anatomists', residents', and medical faculty surgeons' viewpoints on *Megamoulages* based on grade and sex

Participants	Total Number		Academic Levels & Sex											
Medical Students	*N* = 2554		2.5 years (end of semester 5)						7 years (end of semester 14)					
			Male			Female			Male				Female	
			746 (89%)			950 (90%)			371 (91%)				487 (94%)	
Anatomist	*N* = 217		Assistant Professor				Associate Professor				Full Professor			
			Male		Female		Male		Female		Male		Female	
			63 (86%)		43 (88%)		24 (91%)		16 (94%)		54 (93%)		17 (94%)	
Residents	*N* = 824	Fields	GS		OB/GYN		ENT		NS		OS		Urology	
			Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
		Year 1	48 (77%)	17 (%76)	0	54 (89%)	11 (82%)	8 (87%)	24 (75%)	15 (80%)	32 (81%)	9 (89%)	13 (77%)	14 (79%)
		Year 2	27 (85%)	14 (86%)	0	39 (90%)	14 (86%)	7 (86%)	26 (81%)	9 (89%)	37 (86%)	3 (67%)	19 (79%)	19 (84%)
		Year 3	21 (90%)	13 (92%)	0	41 (93%)	14 (93%)	11 (91%)	22 (86%)	11 (91%)	38 (87%)	2 (100%)	12 (83%)	10 (90%)
		Year 4	14 (93%)	11 (91%)	0	37 (95%)	11 (91%)	10 (90%)	19 (89%)	10 (90%)	29 (93%)	5 (80%)	15 (93%)	9 (89%)
Medical Faculty Surgeons	*N* = 405	Fields	Assistant Professor				Associate Professor				Full Professor			
			Male		Female		Male		Female		Male		Female	
		GS	31 (87%)		14 (86%)		23 (72%)		11 (91%)		15 (93%)		10 (90%)	
		OB/Gyn	0		35 (89%)		0		22 (91%)		0		27 (93%)	
		ENT	14 (79%)		13 (85%)		7 (86%)		9 (89%)		8 (87%)		6 (83%)	
		NS	26 (81%)		17 (80%)		21 (81%)		12 (83%)		10 (90%)		8 (87%)	
		OS	12 (75%)		3 (67%)		8 (87%)		2 (100%)		7 (87%)		3 (67%)	
		Urology	7 (71%)		7 (71%)		8 (75%)		4 (75%)		3 (67%)		2 (100%)	

It indicates that the majority of participants agreed with the utilization of *megamoulages*. General Surgery (GS), Obstetrics and Gynecology (OB/GYN), Otorhinolaryngology (ENT), Neurosurgery (NS), and Orthopedic Surgery (OS). The percentage of individuals in agreement (PIA) in each cell is shown as (%)

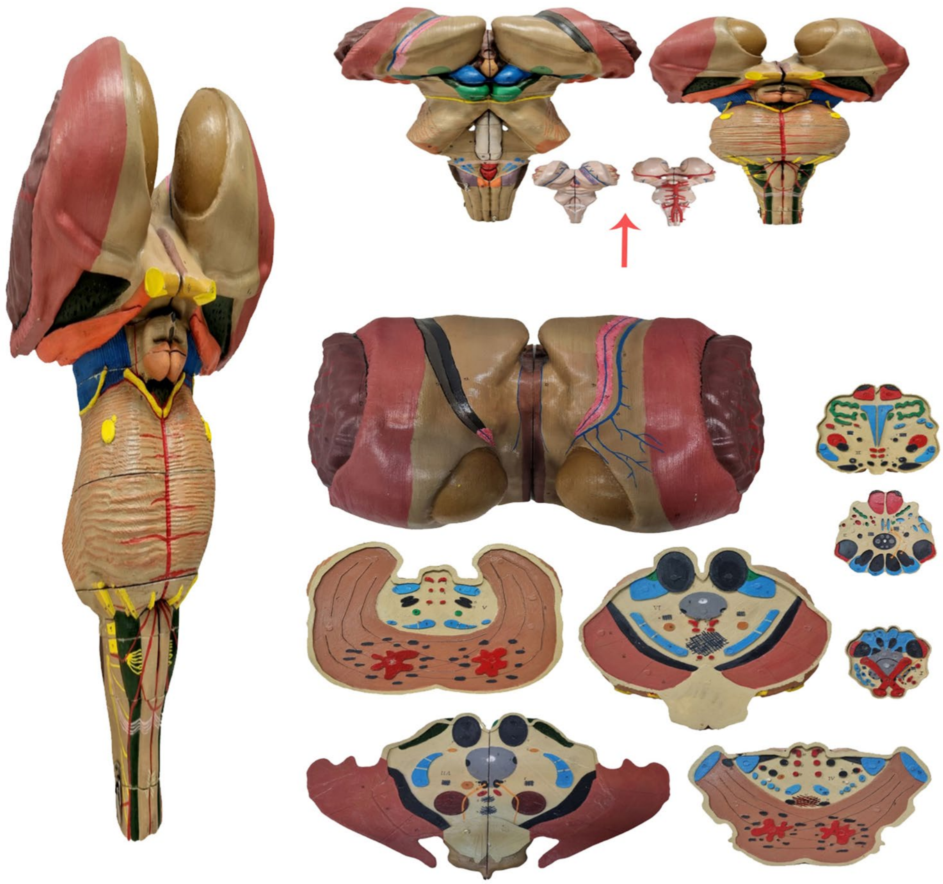

Fig. 1 The Brainstem Megamoulage. Figure 1 showcases a megamoulage that is composed of eight sections. These sections are likely designed to provide a detailed representation of the anatomical structures associated with the brainstem. The red arrow in the figure indicates the conventional moulage, which may serve as a reference point for comparison or to highlight the differences between the megamoulage and traditional moulage

The survey results underscore the significant role of *megamoulages* in medical science, particularly in anatomy education, as highlighted by data from Table 2. The validation process for these models involved multiple levels, starting with the executive team's development of the plan, position, size, structure, and features of anatomical points based on the latest reference materials. Continuous critique and refinement took place while students were exposed to the moulages during production. Expert review was essential, with anatomy professors assessing the designs and trial samples presented to surgeons, anatomists, residents in general surgery, neurosurgery, orthopedic surgery, urology, obstetrics and gynecology, and medical students at national festivals like the "National Festival of Shahid Motahari Medical Education" and the "Festival of New Technologies in Science Education." Feedback from these events informed further development, and the minimum viable product (MVP) method was used for additional validation, sending trial samples to renowned anatomy professors nationwide for their approval.

Among general surgery residents, appreciation for the use of *megamoulages* in learning anatomy was likely correlated with their level of experience in their residency program, although further studies are needed to evaluate this relationship more thoroughly. While residents in other specialties also expressed a positive attitude toward *megamoulages*, this sentiment appeared to be less pronounced compared to that of surgical residents. In Iran, only women are eligible to pursue residency in obstetrics and gynecology; therefore, there is no available data on the perspectives of male residents in this specialized field. In a cross-sectional questionnaire-based study conducted by Atlasi et al. in 2017, involving 237 Iranian medical students from Kashan University of Medical Sciences, it was observed that students of both sexes displayed interest in learning anatomy through various methods, including using notes, plastic models, pictures and diagrams, clinical context, as well as engaging in cadaver dissection and prosection, while they rarely utilized cross-sectional images and web-based resources in their anatomy learning [14]. Similar to Chinese and Jordanian students, Iranian students also tend to adopt a comprehensive

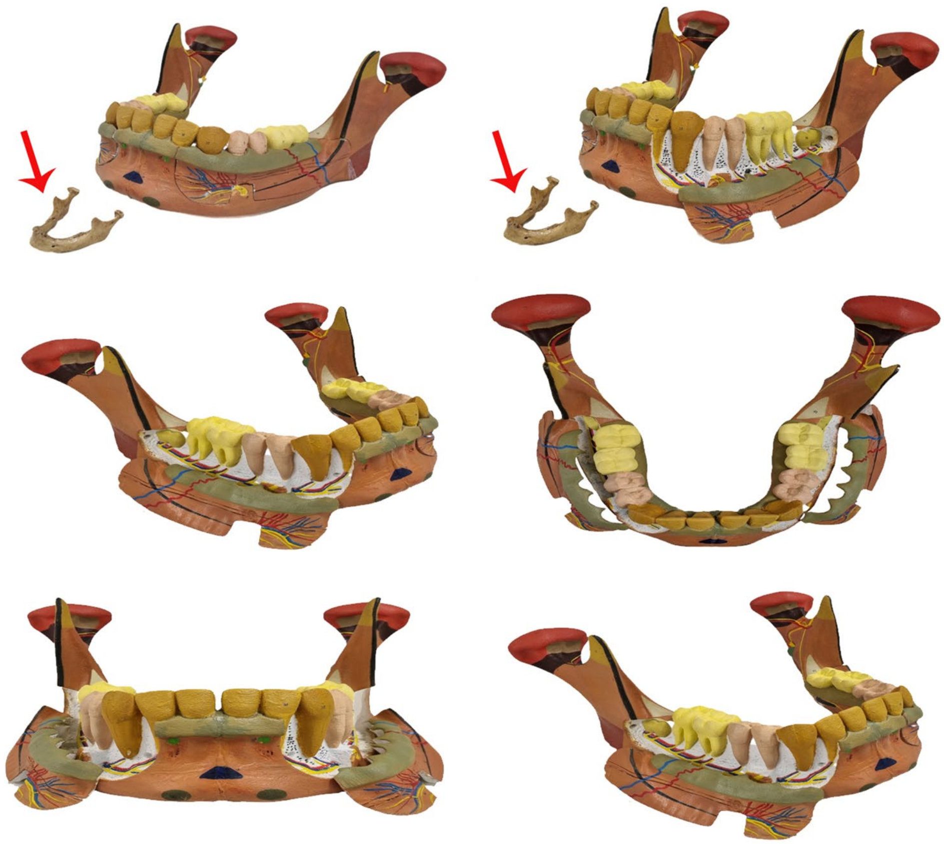

Fig. 2 The Mandible Bone (Megamoulage). This figure presents a megamoulage specifically focused on the mandible bone. This high-detail anatomical model is designed to provide a comprehensive representation of the mandible. The megamoulage likely includes intricate details of the mandible's structure, including the body, ramus, condyles, and teeth. By studying this megamoulage, students and healthcare professionals can gain a deeper understanding of the anatomical features and variations of the mandible bone, which is crucial for various dental and maxillofacial procedures, as well as overall craniofacial anatomy

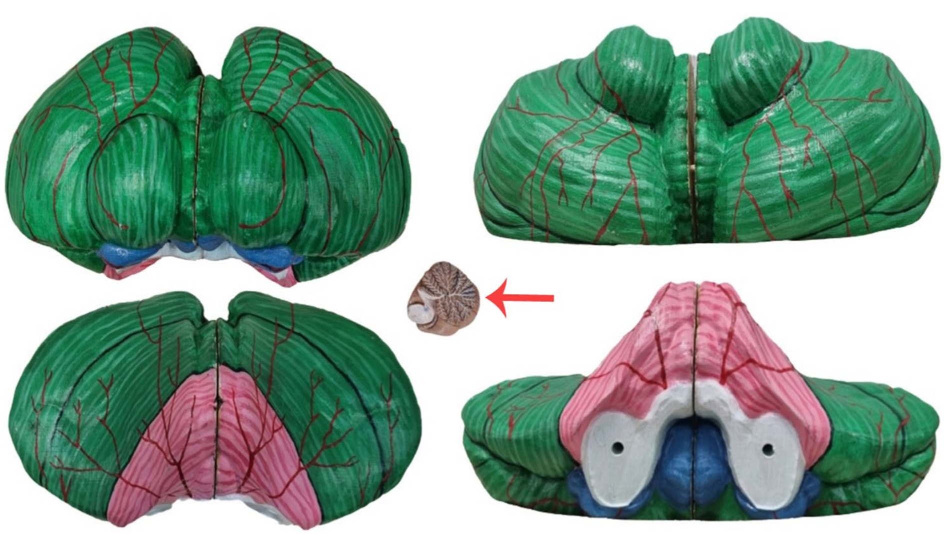

Fig. 3 The Cerebellum (Megamoulage). Figure 3 illustrates a megamoulage dedicated to the cerebellum, a vital structure located at the posterior part of the brain. This anatomical model is designed to provide a detailed representation of the cerebellum's lobes, fissures, and folia, which are the characteristic folds on its surface. The megamoulage likely highlights the intricate network of neurons and connections within the cerebellum, facilitating a comprehensive understanding of its structure and function

Table 3 It indicates the size of produced megamoulages compared to existing ones

Models	Anterior-Posterior Length (cm)	Side to Side Length (cm)	Height (cm)
Brainstem Megamoulage	35	50	60
Brainstem Conventional Moulage	6	8	10
Cerebellum Megamoulage	17	35	18
Cerebellum Conventional Moulage	6	10	4
Mandible Megamoulage	50	35	27
Mandible Conventional Moulage	12	5	6

Table 4 Satisfaction ratings based on smile sheet

Medical Students	Total Students	Type of Moulages	Satisfactory Score (Mean ± SD)		Min-Max Score
			Male	Female	
Gonabad University of Medical Sciences	165	Conventional Moulages	3.4 ± 0.51	3.4 ± 0.69	1–5
		Megamoulages	4.7 ± 0.43 *	4.9 ± 0.32 **	1–5
Kurdistan University of Medical Sciences	181	Conventional Moulages	3.3 ± 0.61	3.5 ± 0.67	1–5
		Megamoulages	4.4 ± 0.42 *	4.8 ± 0.91 **	1–5

The use of (*) for male students and (**) for female students indicates a significant difference in satisfactory scores between the two groups, namely the *Megamoulages* group and the Conventional Moulages group, at Gonabad and Kurdistan University of Medical Sciences. Between the two groups, the asterisk (*) denotes $P < 0.05$ for male students, while the double asterisk (**) represents $P < 0.05$ for female students

Table 5 Average scores of students taught with conventional moulages and *Megamoulages*

Medical Students	Total Students	Type of Moulages	Overall Score [out of 20] (Mean ± SD)	
			Male	Female
Gonabad University of Medical Sciences	**165**	Conventional Moulages	**15.19 ± 3.51**	**16.86 ± 3.01**
		Megamoulages	**18.73 ± 2.45***	**19.02 ± 3.31****
Kurdistan University of Medical Sciences	**181**	Conventional Moulages	**15.63 ± 2.91**	**16.21 ± 2.87**
		Megamoulages	**18.41 ± 3.14***	**18.95 ± 3.28****

The use of (*) for male students and (**) for female students indicates a significant difference in satisfactory scores between the two groups, namely the *Megamoulages* group and the Conventional Moulages group, at Gonabad and Kurdistan University of Medical Sciences. Between the two groups, the asterisk (*) denotes $P < 0.05$ for male students, while the double asterisk (**) represents $P < 0.05$ for female students

approach when learning anatomy [15, 16]. They prefer gaining a general understanding of an anatomical region as a whole, rather than focusing extensively on cross-sectional images or utilizing web-based resources to study individual anatomical structures. This approach aligns with the principles of Gestalt psychology, which suggests that students benefit from acquiring an overall image of an anatomical region, enabling them to comprehend the interrelationships between different anatomical components [17, 18]. Also, the study conducted by Yammine and Violato in 2014 supports the idea that learning methods incorporating visual components can have a substantial impact on the learning process [19]. In a notable study conducted by Yang et al. (2023), the authors examined the impact of 3D-printed models of four bones—vertebrae, pelvic bone, scapula bone, and sphenoid bone—produced in various sizes (50%, 100%, 200%, 300%, and/or 400% of normal size) on the learning outcomes of undergraduate students without prior anatomical knowledge [20]. Their findings indicated that participants utilizing models with the longest diameter exceeding 10 cm achieved remarkably higher scores compared to those using models measuring less than 10 cm. However, there was an exception for the scapula model, in which performance was equivalent across sizes. Additionally, authors believed that beyond the longest diameter, the presence of inherent features of the bones may facilitate learning [20]. It is important to note that the aforementioned study fundamentally differs from our own in that all participants in our study possessed prior anatomical knowledge, and our models were specifically designed not only with a focus on size but also on anatomical accuracy and aesthetic detail; moreover, a QR (quick-response) code was generated for each *megamoulage* produced in this project and affixed to the models, enabling students to easily access all related instructional videos by scanning the QR code, thereby reducing their reliance on traditional resources and fostering greater independence in their learning process. Therefore, *megamoulages* hold the potential to be a valuable resource for anatomy education, leveraging the power of vision to support and enhance the learning process.

In the present study, the majority of full professors in anatomy and medical faculty surgeons emphasized the importance of utilizing *megamoulages* in anatomy education. However, it is noteworthy that the average percentage of younger professors who shared this perspective was slightly lower than that of their more experienced counterparts. In contemporary times, there are various viewpoints on the connection between age and teaching, as highlighted by Weinkle and colleagues [21]. Nevertheless, as educators accumulate experience, they gain valuable insights that help them recognize and nurture students' potential while assisting them in understanding their own worth. This may explain why experienced professors place greater importance on the utilization of *megamoulages* compared to their younger counterparts. The extensive experience and knowledge that seasoned educators possess enable them to appreciate the benefits and significance of incorporating innovative tools like *megamoulages* into the educational process.

The educational initiative led to the design and production of ten unique *megamoulages*, including representations of the spinal cord, brainstem, mandible, cerebellum, vessels of the circulus arteriosus cerebri (Circle of Willis), hippocampus, and more. These *megamoulages* are groundbreaking, being the first of their kind in the country and among the few worldwide. They are entirely original, with no comparable counterparts produced domestically or internationally. For example, the brainstem sectional montage, consisting of eight sections, showcases precise details of nerve pathways, nuclei, adjacencies, and other anatomical features, marking it as the first-ever creation of its kind globally. This study presents figures focusing on the brainstem, mandible bone, and cerebellum as a preliminary investigation. Additional articles will be published in the future, including photographs and findings related to other anatomical structures. Furthermore, this research specifically examines the effects of utilizing brainstem *megamoulages* on students' grades, providing insights into the impact of these advanced models on academic performance. It is important to acknowledge that this study is limited to this specific aspect, and further research is needed to explore the broader effects and potential benefits of *megamoulages* in medical education.

In our study, we also evaluated learning using the first two levels of Kirkpatrick's evaluation model, which comprises four levels. The first level, reaction, measures participant satisfaction and engagement, while the second level, learning, assesses the increase in knowledge or skills resulting from the educational experience. The third level, behavior, examines the transfer of learning to practical application, and the fourth level, results, measures the broader impact on organizational goals. We found that the satisfaction rate among students who utilized *megamoulages* in anatomy teaching was significantly higher compared to those using conventional moulages. This level of evaluation was assessed through feedback forms, indicating that the innovative use of *megamoulages* positively influenced students' perceptions of their learning experience. Furthermore, at the second level of evaluation, the incorporation of *megamoulages* in practical classes resulted in a significant enhancement in students' final grades compared to those who exclusively used conventional moulages. These findings suggest that *megamoulages* not only improved student satisfaction but also contributed to better academic performance, underscoring their effectiveness in anatomy education. While our study primarily focused on the first two levels, future research could explore how *megamoulages* influence behavior and results in medical training.

Educators have increasingly focused on student satisfaction, as research indicates that higher satisfaction levels are linked to increased retention, improved academic performance, and overall enjoyment among students [22, 23]. A review study by Stokes-Parish et al. (2018) emphasized the widely accepted belief that moulage plays a crucial role in simulation-based education by enhancing realism and promoting learner engagement [24]. Additionally, a review by Chytas et al. (2020) demonstrated that the use of three-dimensional printing (3DP) in anatomy education leads to favorable outcomes in academic performance compared to 2D images [25]. Specifically, teaching with 3D printed models, such as skulls, resulted in significantly higher post-test scores compared to traditional models [26, 27]. Multiple studies consistently show that 3D printed models are regarded as effective tools for anatomy learning, with over 70% of participants expressing their effectiveness [26, 28]. Furthermore, a study by Swetha and Thenmozhi found that combining innovative technologies, such as visual aids, with traditional teaching methods enhances students' comprehension of gross anatomy and ultimately improves academic performance [29].

Therefore, we believe that such a teaching method, the use of *megamoulages*, can likely enhance learning for several reasons. They provide realistic representations that probably boost student engagement and understanding, improve retention of complex anatomical information, and increase accessibility in settings with limited cadaver materials. *Megamoulages* also likely encourage active learning through model interaction, leading to better academic performance and promoting collaboration among students. Additionally, they probably cater to various learning styles by offering visual, tactile, and kinesthetic experiences. To thoroughly investigate the specific impacts of *megamoulages*, further studies are needed to examine how they can affect learning outcomes in undergraduate and postgraduate students, as well as in medical students across different semesters.

Conclusions

The integration of *megamoulages* in medical education, especially in anatomy, is set to enhance training significantly in the next decade. The use of such teaching methods can provide realistic opportunities for students and healthcare professionals to improve their skills. Our study shows strong awareness among students and professors regarding the importance of *megamoulages*. Evaluated through Kirkpatrick's model, *megamoulages* received high scores in the first two levels—reaction and learning—indicating positive responses and knowledge acquisition. Future semesters will assess the higher levels of Kirkpatrick's model, including the transfer of knowledge to behavior changes (level 3), and impacts on outcomes (level 4). These evaluations will deepen our understanding of the effectiveness of *megamoulages* in medical education.

Study limitations and future directions

One significant limitation encountered in the creation of integrated *megamoulages* was the lack of access to suitable 3D printing technology in Iran, which impeded the integration process. *Megamoulages* represent a considerable advancement in medical education and possess substantial potential for future applications, as these highly detailed anatomical models provide realistic representations of anatomical structures, thereby enhancing both learning experiences and surgical training. As technology continues to progress, the integration of *megamoulages* with augmented reality (AR) and virtual reality (VR) holds promise for further enriching the educational experience. With improved accessibility and broader adoption, *megamoulages* could revolutionize medical education by offering comprehensive and immersive learning opportunities for students and healthcare professionals alike. Moreover, the production of strategic *megamoulages* poses challenges due to their complexity; creating these models is both time-consuming and requires an in-depth study of related texts and articles to ensure that no anatomical detail is overlooked in the design process. Additionally, the design of *megamoulages* must be entirely innovative, presenting new perspectives on the 3D structure of the body. In this project, considerable time was dedicated to the design phase to ensure that the models achieved maximum precision, creativity, and complexity while accurately resembling human anatomy. Another limitation that affected production speed was the manual coloring of the *megamoulages*, performed by anatomists to ensure accurate representation and verify the orientation and proximity of anatomical structures. This manual process significantly increased the production time. Accessibility issues in engaging surgeons, anatomists, and residents for surveys further contributed to delays in production. Additionally, errors made during the initial design and production phases necessitated the reproduction of several *megamoulages*. A further technical limitation involved blockages in the nozzle of the 3D printer, which also hindered production efficiency.

High-fidelity simulation technology stands as one of the most significant advancements in the field of educational simulators, having been utilized extensively in various clinical domains, albeit to a lesser extent in anatomy education. This technology enables the creation of layered models that closely resemble human tissues, each exhibiting distinct densities akin to the layers of the abdominal wall or any multi-layered organ. Furthermore, the advent of artificial intelligence has the potential to innovate teaching methods significantly. It is now feasible to produce AI-based interactive models utilizing large language models (LLMs). If these interactive models are designed as large, articulated structures that clearly display all anatomical features, they could greatly enhance student engagement and enthusiasm for learning. Currently, the development of robots based on LLM technology is underway, indicating a promising direction for future educational tools.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-025-07058-1.

Supplementary Material 1

Acknowledgements

The authors would like to express their gratitude to the Medical Faculty of Gonabad and Kurdistan Medical Schools for granting permission to conduct this study. Furthermore, the authors extend their sincere appreciation to the students and professors who willingly participated in the research study and provided valuable feedback that contributed to the findings. We also thank the creators of POE AI tools for their assistance, as we utilized POE software to edit the grammar of our article.

Author contributions

All the professors actively participated in the study, taking on various responsibilities such as study design, creating megamoulages, reviewing questionnaires, writing proposals, and publishing articles.

Data availability

Any data used and analyzed in our study are available from the corresponding authors upon reasonable request.

Declarations

Ethics approval and consent to participate

Before their participation, all students were provided with information about the course project and gave their voluntary informed consent by signing the consent form. Data analysis was conducted retrospectively after the completion of the course and final examination. All experimental protocols were approved by the ethical committee of Gonabad University of Medical Sciences, Gonabad, Iran.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Operating Room and Anesthesia, Faculty of Nursing and Midwifery, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2]Department of Anatomical Sciences, Faculty of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran
[3]Cellular and Molecular Research Center, Birjand University of Medical Sciences, Birjand, Iran
[4]Clinical Research Development Unit of Tabriz Valiasr Hospital, Tabriz University of Medical Sciences, Tabriz, Iran
[5]Department of Anatomy, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran
[6]Faculty of Nursing and Midwifery, and Nursing Research center, Gonabad University of Medical Sciences, Gonabad, Iran
[7]Department of Pediatric Nephrology, Faculty of Medicine, Gonabad University of Medical Sciences, Gonabad, Iran

[8]Department of Medical-Surgical Nursing, Faculty of Nursing, Social Development & Health Promotion Research Center, Gonabad University of Medical Sciences, Gonabad, Iran
[9]Student Research Committee, Faculty of Medicine, Gonabad University of Medical Sciences, Gonabad, Iran
[10]Department of Anatomy, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran
[11]Department of Anatomy, Faculty of Medicine, Gonabad University of Medical Sciences, Gonabad, Iran

Received: 7 March 2024 / Accepted: 25 March 2025
Published online: 04 April 2025

References

1. Pereira JA, et al. Effectiveness of using blended learning strategies for teaching and learning human anatomy. Med Educ. 2007;41(2):189–95.
2. Taheri A. The anatomy illustration in some of the Western and Iranian medical manuscripts. J Res History Med. 2020;9(3):163–78.
3. Estai M, Bunt S. Best teaching practices in anatomy education: A critical review. Annals Anatomy-Anatomischer Anzeiger. 2016;208:151–7.
4. Khalil MK, Abdel Meguid EM, Elkhider IA. Teaching of anatomical sciences: A blended learning approach. Clin Anat. 2018;31(3):323–9.
5. Cooke RA. A moulage museum is not just a museum: wax models as teaching instruments. Virchows Arch. 2010;457:513–20.
6. Stokes-Parish J, Duvivier R, Jolly B. Expert opinions on the authenticity of moulage in simulation: a Delphi study. Adv Simul. 2019;4(1):1–10.
7. Taylor T, Kolcun K, Tornwall J. Application of the nursing process using moulage as a Problem-Based approach to teaching dermatologic content. Nurs Educ Perspect. 2023;44(1):63–5.
8. Neave R. Pictures in the round: moulage and models in medicine. J Audiov Media Med. 1989;12(2):80–4.
9. Eastwood KW, Harris A, Armstrong JB. A disaster medicine course for Canadian medical students: first implementation of a large-scale mass-casualty simulation. Can J Emerg Med, 2023: pp. 1–4.
10. Charnetski MD. Simulation methodologies. Comprehensive Healthcare Simulation: Operations, Technology, and Innovative Practice. 2019:27–45.
11. Kirkpatrick DL. The four levels of evaluation. Evaluating corporate training: Models and issues. 1998:95–112.
12. Steinert Y, et al. A systematic review of faculty development initiatives designed to improve teaching effectiveness in medical education: BEME guide 8. Med Teach. 2006;28(6):497–526.
13. Afshar M, et al. Flipped and Peer-Assisted teaching: a new model in virtual anatomy education. BMC Med Educ. 2024;24(1):722.
14. Atlasi MA, et al. Learning styles and strategies preferences of Iranian medical students in gross anatomy courses and their correlations with gender. Anat Cell Biology. 2017;50(4):255–60.
15. Mitchell BS, et al. A cross-cultural comparison of anatomy learning: learning styles and strategies. Anat Sci Educ. 2009;2(2):49–60.
16. Abdallah AR, Al-Zalabani A, Alqabshawi R. Preferred learning styles among prospective research methodology course students at Taibah university, Saudi Arabia. J Egypt Public Health Assoc. 2013;88(1):3–7.
17. Miller R. Approaches to learning Spatial relationships in gross anatomy: perspective from wider principles of learning. Clin Anatomy: Official J Am Association Clin Anatomists Br Association Clin Anatomists. 2000;13(6):439–43.
18. Ye Z, Xue C, Lin Y. Visual perception based on gestalt theory. in Intelligent Human Systems Integration 2021: Proceedings of the 4th International Conference on Intelligent Human Systems Integration (IHSI 2021): Integrating People and Intelligent Systems, February 22–24, 2021, Palermo, Italy. 2021. Springer.
19. Yammine K, Violato C. A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. Anat Sci Educ. 2015;8(6):525–38.
20. Yang JX, et al. Size matters! Investigating the effects of model size on anatomy learning. Anat Sci Educ. 2023;16(3):415–27.
21. Weinkle LJ, Stratford JM, Lee LM. Voice in digital education: the impact of instructor's perceived age and gender on student learning and evaluation. Anat Sci Educ. 2020;13(1):59–70.
22. Costouros T. Jigsaw cooperative learning versus traditional lectures: impact on student grades and learning experience. Teach Learn Inq. 2020;8(1):154–72.
23. Alqasa KMA, Afaneh JAA. Active learning techniques and student satisfaction: role of classroom environment. Eurasian J Educational Res. 2022;98(98):85–100.
24. Stokes-Parish JB, Duvivier R, Jolly B. Investigating the impact of moulage on simulation engagement—a systematic review. Nurse Educ Today. 2018;64:49–55.
25. Chytas D, et al. Three-dimensional printing in anatomy teaching: current evidence. Surg Radiol Anat. 2020;42:835–41.
26. Chen S, et al. The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trail. Sci Rep. 2017;7(1):575.
27. Smith CF, et al. Take away body parts! An investigation into the use of 3D-printed anatomical models in undergraduate anatomy education. Anat Sci Educ. 2018;11(1):44–53.
28. Mogali SR, et al. Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. Anat Sci Educ. 2018;11(1):54–64.
29. Swetha S, Thenmozhi M. A survey on evaluation of students' perception in anatomy teaching methodologies. Drug Invention Today, 2020. 13(1).

Publisher's note