

Design, implementation, and evaluation of an AI-assisted music-based multimedia learning intervention for medical histology education: A mixed-methods study

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Abstract

Background

Histology is a visually demanding subject that requires students to integrate complex microscopic images with extensive terminology, often resulting in cognitive overload and reduced engagement. Although multimedia learning, educational music, and generative artificial intelligence (AI) have each shown educational potential, their combined application in routine histology teaching has received limited attention. This study aimed to design, implement, and evaluate an AI-assisted music-based multimedia intervention for histology education.

Methods

A quasi-experimental mixed-methods study with a historical control group was conducted among 202 medical sciences (Medicine, Dentistry, Radiotherapy, Anatomical Sciences) students at Babol University of Medical Sciences, Iran. The intervention group ($n = 101$) received AI-assisted music-based multimedia clips developed using ChatGPT, DeepSeek, SUNO.ai, and Camtasia to reinforce key histology concepts after each lecture, while the historical control group ($n = 101$) received conventional instruction. Educational effectiveness was evaluated using the first two levels of the Kirkpatrick Evaluation Model through a validated student satisfaction questionnaire (SSIM_sQ), an intervention-specific evaluation questionnaire, qualitative thematic analysis, and final histology examination scores.

Results

Compared with conventional instruction, the intervention was associated with significantly higher student satisfaction across all questionnaire domains ($P < 0.0001$) and significantly higher final examination scores (17.41 ± 2.26 vs. 16.10 ± 2.34 , $P < 0.0001$). Students also rated the intervention highly for motivation, educational effectiveness, and technical quality. Qualitative analysis identified five themes highlighting enhanced learning and knowledge retention, increased engagement, positive emotional learning experiences, learner-centered recommendations for improvement, and both opportunities and challenges associated with AI integration in medical education.

Conclusions

AI-assisted music-based multimedia learning represents a feasible, theory-informed approach to supporting medical histology education. Integrating generative AI with multimedia learning principles and faculty-guided instructional design was associated with improved student engagement, perceived learning, satisfaction, and academic performance. Further multicenter studies are needed to evaluate its long-term educational impact and generalizability.

Introduction

Histology is a fundamental component of medical education, providing the microscopic basis for understanding normal tissue architecture, organ function, and disease processes. Despite its importance, histology is widely recognized as one of the most challenging preclinical subjects because students must integrate complex visual information with extensive factual knowledge and specialized terminology (1–3). These learning demands place considerable pressure on working memory, frequently resulting in cognitive overload, mental fatigue, reduced attention, and declining motivation during conventional lecture-based instruction (4, 5).

To address these challenges, health professions education has increasingly adopted learner-centered instructional approaches that promote active engagement and meaningful learning (6). Among these, microlearning and multimedia-enhanced instruction have shown considerable promise by presenting educational content in concise, engaging, and cognitively manageable formats (7, 8). Their effectiveness is supported by Mayer's Cognitive Theory of Multimedia Learning, which proposes that meaningful learning occurs when learners actively integrate complementary verbal and visual information through separate cognitive channels while minimizing unnecessary cognitive processing (9, 10). Similarly, Cognitive Load Theory emphasizes the importance of reducing extraneous cognitive load to optimize learners' limited cognitive resources for schema construction and long-term retention (11).

Music has also emerged as a potentially valuable educational resource because of its cognitive and motivational benefits. Previous studies have demonstrated that educational music can facilitate memory encoding and retrieval, improve mood, reduce stress, and enhance learner engagement (12–15). In disciplines requiring the acquisition of visually complex knowledge, such as histology, music-based reinforcement may provide an enjoyable and memorable strategy for consolidating key concepts while reducing the perceived burden of learning (16).

Although these educational approaches are promising, developing customized multimedia resources—including educational songs—has traditionally required substantial time, technical expertise, and financial investment, limiting their routine adoption in medical education (17). Recent advances in generative artificial intelligence (AI) have created new opportunities to overcome these barriers. AI-powered content generation platforms can rapidly transform educational materials into multimedia learning resources aligned with specific learning objectives, thereby reducing production time and increasing accessibility for educators. For example, music-generation platforms such as SUNO.ai enable instructors to convert educational text into original musical content within minutes, making the creation of discipline-specific educational resources considerably more feasible (18–20).

Despite increasing interest in multimedia learning, music-assisted instruction, and artificial intelligence, these approaches have largely been investigated independently (21–23). Existing AI applications in medical education have primarily focused on large language models, automated assessment, feedback generation, and intelligent tutoring systems, whereas music-based educational interventions have generally relied on conventionally produced materials rather than AI-assisted content generation (17, 20,

24). Consequently, evidence remains limited regarding the feasibility and educational effectiveness of integrating AI-generated music into routine classroom teaching as a theory-informed instructional strategy. Moreover, little is known about whether generative AI can support educators in rapidly developing standardized, low-cost multimedia learning resources while maintaining alignment with established educational theories and curriculum objectives.

Therefore, this study aimed to design, implement, and evaluate an AI-assisted music-based educational intervention for medical histology education. AI-generated musical clips created using SUNO.ai were integrated into routine classroom teaching immediately after each lecture to reinforce key concepts. Guided by the Cognitive Theory of Multimedia Learning and Cognitive Load Theory, the intervention was designed as a practical, scalable, and theory-informed instructional strategy for supporting learner engagement and knowledge retention. Its educational effectiveness was evaluated using the first two levels of the Kirkpatrick Evaluation Model through a mixed-methods assessment of students' reactions, learning experiences, and academic performance.

Methods

2.1 Study design

This study employed a quasi-experimental mixed-methods design with a historical control group to design, implement, and evaluate an AI-assisted music-based educational intervention in histology education. The intervention was evaluated according to the first two levels of the Kirkpatrick Evaluation Model: students' reactions (Level 1) and learning outcomes (Level 2). Quantitative data were obtained from structured questionnaires and final histology examination scores, whereas qualitative data were collected through open-ended questions exploring students' experiences, perceptions, and suggestions regarding the intervention.

2.2 Study setting and participants

The intervention was implemented over two consecutive academic semesters (2025–2026) among medical students enrolled in medicine, dentistry, and radiotherapy, as well as master's students in anatomical sciences, at Babol University of Medical Sciences (Medicine, Dentistry, Radiotherapy, Anatomical Sciences), Iran.

A total of 202 students participated in the study, including 101 in the intervention group and 101 in the historical control group. The historical control group consisted of students who had completed the same histology course before implementation of the intervention.

Both groups followed the same curriculum, learning objectives, course structure, and conventional teaching approach. The only educational difference was the addition of AI-assisted music-based educational clips as a supplementary learning activity for the intervention group.

At the end of the course, students in both groups were invited to complete the Short Student Satisfaction with Innovative Teaching Methods Questionnaire (SSIM_sQ) to evaluate satisfaction with the educational approach (25). Students in the intervention group also completed an intervention-specific questionnaire assessing their perceptions of the AI-assisted music-based educational clips. Participation was voluntary, and informed consent was obtained before questionnaire completion.

2.3 Development and implementation of the AI-assisted music-based educational intervention

The intervention was developed in accordance with Mayer's Cognitive Theory of Multimedia Learning and Cognitive Load Theory. For some lectures, the course instructor identified the key learning objectives and essential histological concepts based on the official curriculum. Educational lyrics summarizing these concepts were prepared using scientifically accurate language and reviewed by a histology faculty member to ensure accuracy and alignment with the course content.

The lyrics were subsequently refined using ChatGPT (OpenAI, San Francisco, CA, USA) and DeepSeek (DeepSeek AI, Hangzhou, Zhejiang, China) to improve linguistic clarity and rhythmic flow while preserving scientific accuracy. The finalized lyrics were then converted into original educational musical clips using SUNO.ai (Suno AI, Cambridge, MA, USA).

The musical clips were combined with histological images, labeled diagrams, and key learning points using Camtasia (TechSmith Corporation, East Lansing, MI, USA) to create short multimedia educational videos. All materials were reviewed by the course instructor before classroom implementation.

Following each lecture, the corresponding AI-generated multimedia clip was presented as a brief review of the key concepts discussed during that session. A schematic overview of the intervention development process is shown in Fig. 1.

2.4 Evaluation framework and outcome measures

The intervention was evaluated using the first two levels of the Kirkpatrick Evaluation Model. Level 1 assessed students' reactions, whereas Level 2 evaluated learning outcomes through academic achievement.

Level 1: Students' reactions

Students' reactions were assessed using two quantitative questionnaires and one qualitative evaluation.

Student satisfaction assessment

Student satisfaction was assessed in both groups using the Short Student Satisfaction with Innovative Teaching Methods Questionnaire (SSIM_sQ), a previously validated instrument for evaluating innovative teaching methods in basic medical sciences (25). The questionnaire comprised six items scored on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree), evaluating enjoyment of learning,

motivation to study, perceived contribution to future professional skills, enhancement of learning, long-term knowledge retention, and overall preference for the instructional approach.

Intervention-specific evaluation

Students in the intervention group completed an intervention-specific questionnaire consisting of 15 five-point Likert-scale items evaluating:

1. **Motivational outcomes:** reduced learning fatigue, increased interest in histology, preference for the intervention, perceived attractiveness of the course, and willingness to use similar resources in other medical courses.
2. **Perceived educational effectiveness:** long-term knowledge retention, improved understanding of histology, learning of basic and complex concepts, simplification of difficult concepts, and usefulness for examination review.
3. **Technical and instructional quality:** audiovisual quality, speech quality, visual design, clip duration, and willingness to recommend the educational clips.

Qualitative evaluation

The intervention-specific questionnaire also included 11 open-ended questions exploring students' experiences, perceived educational value, effective components of the intervention, opportunities and challenges of AI-assisted education, emotional engagement, suggestions for improvement, and potential application in other courses.

Qualitative responses were independently coded by the research team and grouped into broader themes through iterative discussion and consensus.

Level 2: Learning outcomes

Learning outcomes were evaluated by comparing final histology examination scores between the intervention and historical control groups. Both cohorts completed the same curriculum and learning objectives, and final examination scores served as the objective indicator of academic achievement.

2.5 Statistical analysis

Continuous variables were expressed as mean $\pm$ standard deviation (SD), and categorical variables as frequencies and percentages.

Comparisons of satisfaction scores between groups were performed using the independent-samples *t*-test or Mann–Whitney *U* test, as appropriate. Comparisons among satisfaction domains were conducted using the Kruskal–Wallis test followed by Dunn's multiple comparisons test. Final examination scores

were compared using the independent-samples *t*-test or Welch's *t*-test according to variance assumptions.

All statistical analyses were performed using appropriate statistical software, and a two-sided $P < 0.05$ was considered statistically significant.

2.6 Ethical considerations

The study was approved by the Ethics Committee of Babol University of Medical Sciences (IR.MUBABOL.HRI.REC.1405.052). Participation was voluntary, and written informed consent was obtained from all participants before data collection.

Questionnaire responses were collected anonymously and used exclusively for research purposes. Participation did not influence students' academic evaluation or course grades.

Result

3.1 Participant characteristics

A total of 202 students participated in the study, including 101 students in the intervention group and 101 in the historical control group. Demographic and academic characteristics are summarized in Table 1. In both groups, males slightly outnumbered females, and most students were enrolled in the second academic semester (67.32% in the intervention group and 58.41% in the historical control group).

Table 1

Demographic and academic characteristics of students in the intervention and historical control groups

Variable	Category	Intervention group (n = 101), n (%)	Historical control group (n = 101), n (%)
Gender	Female	42 (41.58%)	49 (48.51%)
	Male	59 (58.41%)	51 (50.49%)
Academic semester	Semester 1	33 (32.67%)	42 (41.58%)
	Semester 2	68 (67.32%)	59 (58.41%)
Field of study	Medicine	53 (52.47%)	44 (43.56%)
	Dentistry	30 (29.70%)	37 (36.63%)
	Radiotherapy	11 (10.89%)	16 (15.84%)
	Anatomical Sciences (Master's)	7 (6.93%)	4 (3.96)
Age group (years)	18–19	51 (50.49%)	57 (56.43)
	20–24	34 (33.66%)	32 (31.68%)
	24< (25–39)	16 (15.84%)	12 (11.88%)
High School GPA	17–20	98 (97%)	97 (96.03%)

Data are presented as n (%). The intervention group received the AI-assisted music-based educational intervention, whereas the historical control group completed the same histology course before implementation of the intervention under conventional teaching. Grade point averages were reported according to the Iranian 0–20 grading system.

Variable	Category	Intervention group (n = 101), n (%)	Historical control group (n = 101), n (%)
	15-16.99	1 (1%)	4 (3.97%)
	12-14.99	2 (2%)	0 (0%)
Cumulative GPA (CGPA)	N/A (first semester students)	27 (26.73%)	32 (31.68%)
	17–20	27 (26.73%)	25 (24.75%)
	15-16.99	29 (28.71%)	28 (27.72%)
	12-14.99	18 (17.82%)	16 (15.84%)
Data are presented as n (%). The intervention group received the AI-assisted music-based educational intervention, whereas the historical control group completed the same histology course before implementation of the intervention under conventional teaching. Grade point averages were reported according to the Iranian 0–20 grading system.			

Medicine was the most common field of study in both groups (52.47% and 43.56%, respectively), followed by dentistry. Most participants were 18–19 years of age and had high school GPAs between 17 and 20 on the Iranian 0–20 grading scale. Among students with available cumulative GPA (CGPA) records, most had CGPAs between 15 and 20, whereas 26.73% of the intervention group and 31.68% of the historical control group were first-semester students and therefore did not yet have a CGPA. Overall, the demographic and academic profiles of the intervention and historical control groups were broadly comparable (Table 1).

3.2 Comparison of students' satisfaction between the control and intervention groups (SSIM_sQ)

Students who received the AI-assisted music-based educational intervention reported significantly greater overall satisfaction with the educational approach than students receiving conventional instruction alone (3.817 ± 0.171 vs. 3.116 ± 0.077 , $P = 0.0238$) (Fig. 2C).

Compared with the historical control group, students in the intervention group reported significantly higher enjoyment of learning (4.158 ± 0.090 vs. 3.218 ± 0.092 , $P < 0.0001$), motivation to study histology (4.059 ± 0.097 vs. 3.347 ± 0.105 , $P < 0.0001$), perceived enhancement of learning (4.069 ± 0.088 vs. 3.218 ± 0.092 , $P < 0.0001$), perceived long-term retention of knowledge (3.594 ± 0.106 vs. 3.139 ± 0.114 , $P = 0.0030$), and preference for the educational method (3.960 ± 0.098 vs. 2.891 ± 0.114 , $P < 0.0001$).

(Fig. 2D–I). In contrast, perceived contribution to future professional skills did not differ significantly between groups (3.059 ± 0.080 vs. 2.881 ± 0.088 , $P = 0.2317$) (Fig. 2F).

Within the intervention group, the highest ratings were observed for enjoyment of learning (4.158 ± 0.090), perceived enhancement of learning (4.069 ± 0.088), motivation to study (4.059 ± 0.097), and preference for the educational approach (3.960 ± 0.098). Perceived contribution to future professional skills received the lowest mean score (3.059 ± 0.080). By comparison, responses in the historical control group remained relatively homogeneous, with consistently lower ratings across all questionnaire domains (Fig. 2A–B).

Overall, the findings demonstrated substantially greater student satisfaction when conventional histology teaching was supplemented with AI-assisted music-based educational clips.

3.3 Evaluation of the AI-generated music-based educational clips (Intervention questionnaire)

Students in the intervention group evaluated the AI-generated music-based educational clips positively across all three domains: motivational outcomes, perceived educational effectiveness, and technical and instructional quality (Fig. 3).

Ratings within the motivational domain ranged from 3.822 ± 0.093 to 4.139 ± 0.077 , indicating high levels of interest, engagement, and willingness to use similar educational resources in other medical courses. No statistically significant differences were observed among the motivational items (Fig. 3A).

Within the educational effectiveness domain, all items received favorable ratings (3.780 ± 0.093 – 4.119 ± 0.070). The usefulness of the clips for examination review received the highest score and was rated significantly higher than their perceived contribution to long-term learning ($P = 0.0167$) (Fig. 3B).

Technical and instructional quality was also rated positively. Students expressed high satisfaction with the audiovisual quality, presentation design, and overall usability of the clips. Clip duration received the highest rating (approximately 4.0 ± 0.1), significantly exceeding the ratings for speech quality ($P < 0.001$) and overall recommendation ($P < 0.01$) (Fig. 3C).

Across the three domains, perceived educational effectiveness achieved the highest overall score (4.050 ± 0.077), followed by motivational outcomes (3.988 ± 0.037). Technical and instructional quality received slightly lower, although still favorable, ratings (3.826 ± 0.036), with presentation speed receiving the lowest individual score (3.570 ± 0.081). Overall, students rated the educational effectiveness (3.945 ± 0.036) and motivational value (3.988 ± 0.037) of the AI-generated music-based clips significantly higher than their technical characteristics (3.826 ± 0.036 ; $P = 0.0032$ and $P = 0.0379$, respectively) (Fig. 3D).

Collectively, these findings indicate that students regarded the AI-generated music-based clips as educationally valuable, motivating, and technically appropriate learning resources.

3.4 Subgroup analysis of overall intervention scores

Subgroup analyses examined whether overall evaluations of the AI-assisted music-based educational intervention differed according to demographic and academic characteristics (Fig. 4).

Female students reported significantly higher overall intervention scores than male students (3.938 ± 0.049 vs. 3.671 ± 0.052 , $P = 0.0006$) (Fig. 4A).

Overall evaluations also differed according to age. Students aged 20–24 years (3.941 ± 0.069) and those aged ≥ 25 years (3.963 ± 0.086) assigned significantly higher scores than students aged 18–19 years (3.708 ± 0.048) ($P = 0.0340$ and $P = 0.0249$, respectively), whereas no significant difference was observed between the two older age groups (Fig. 4B).

Academic discipline also influenced overall evaluations ($P = 0.0128$). Postgraduate students in anatomical sciences reported the highest scores compared with medical students (4.152 ± 0.117 vs. 3.743 ± 0.049) (Fig. 4C).

No significant differences were observed among cumulative GPA categories, indicating comparable evaluations regardless of previous academic achievement (Fig. 4D).

Overall, favorable evaluations were observed across all demographic and academic subgroups.

3.5 Qualitative findings

Thematic analysis of students' responses to the 11 open-ended questions identified five overarching themes describing learners' perceptions of the AI-assisted music-based educational intervention (Table 2). These themes were broadly aligned with the study's conceptual framework, including Mayer's Cognitive Theory of Multimedia Learning, Cognitive Load Theory, and the first two levels of the Kirkpatrick Evaluation Model.

Table 2

Thematic analysis of students' perceptions of the AI-assisted music-based educational intervention

Theme	<i>Relationship to conceptual framework</i>	<i>Supporting questions</i>	<i>Major subthemes identified</i>	<i>Representative findings from students' responses</i>
1. Enhanced learning and knowledge retention	Mayer; Kirkpatrick Level 2	Q2, Q4, Q5, Q9, Q11	Better understanding; memory retention; exam preparation; transfer to other courses	Music (n = 61) and visual images (n = 41) were perceived as the main contributors to learning, improving understanding, long-term retention, and supporting application of the intervention to other basic medical science courses.
2. Motivation and learner engagement	Kirkpatrick Level 1 (Reaction)	Q1, Q5, Q6, Q9, Q11	Engagement; motivation; enjoyment; recommendation	Approximately 67% of students reported greater classroom engagement than during conventional lectures. Most assigned high recommendation scores (7.79 ± 0.16 out of 10) and perceived the intervention as enjoyable, innovative, motivating, and effective in reducing classroom fatigue.
3. Positive emotional and cognitive experience	Cognitive Load Theory	Q2, Q4, Q9, Q11	Emotional engagement; attention; reduced learning burden	Students perceived the clips as enjoyable and emotionally engaging, reporting that music and synchronized visuals maintained attention, reduced cognitive burden, and enhanced the overall learning experience.
4. Learner-centered refinement	Learner-centered instructional design	Q3, Q7, Q8	Personalization, subtitles, student involvement	Participants recommended greater personalization and learner participation.
5. Opportunities and implementation challenges	Educational innovation	Q4, Q10	Innovation; scientific accuracy; technical barriers	Students viewed AI as an innovative educational tool but highlighted the need for scientific validation, faculty oversight, technical expertise, and adequate time for implementation.
Themes were identified through thematic analysis of responses to 11 open-ended questions. The table summarizes the main themes, subthemes, and key findings describing students' perceptions of the AI-assisted music-based educational intervention.				

Enhanced learning and knowledge retention

Students consistently reported that combining music with synchronized visual materials facilitated understanding and reinforced long-term retention of histology concepts. Music (n = 61) and visual images (n = 41) were identified as the most influential components supporting learning. Many participants also recommended extending this instructional approach to other basic medical science courses, particularly anatomy, physiology, and biochemistry. As one student stated, “The rhythm made difficult concepts much easier to remember” (Participant 37, Anatomical Sciences). Another participant commented, “This approach would also be valuable for physiology and histology courses across different semesters. It is especially useful for subjects that rely heavily on visual learning because students can see and hear the content simultaneously” (Participant 51, Medicine).

Motivation and learner engagement

Students described the intervention as substantially more engaging than conventional lectures. Approximately 67% of participants reported greater classroom engagement than during traditional teaching, and the intervention received high recommendation scores (7.79 ± 0.16 out of 10). Many participants characterized the clips as enjoyable, motivating, and effective in reducing classroom fatigue. One student noted, “For a first attempt, I really enjoyed it. However, the lyrics could be more engaging. I also think that collaborating with poetry or arts groups, rather than relying solely on AI, might result in richer and more meaningful educational songs” (Participant 8, Radiotherapy). Another remarked, “The clip relieved the fatigue I felt after class while effectively reviewing the entire lesson. I truly appreciated it” (Participant 21, Medicine).

Positive emotional and cognitive learning experience

Students frequently described the musical clips as memorable, enjoyable, and emotionally engaging. They emphasized that integrating music with synchronized visual materials helped maintain attention, reduced perceived mental effort, and transformed histology into a more enjoyable learning experience. As one participant explained, “The clip reflected the instructor's genuine commitment to helping us understand and retain the material. It not only motivated me to use this learning approach but also made me reflect on my own responsibility to study harder” (Participant 69, Medicine).

Learner-centered refinement of the intervention

Students also offered constructive suggestions for improving the educational clips, including greater personalization of musical style, subtitles, enhanced visual materials, improved pronunciation, and increased student involvement in developing future educational resources. One participant suggested, “The images could be enlarged to make important structures more visible, especially for visual memory,

and the text would be better presented as subtitles rather than occupying a large portion of the screen” (Participant 12, Medicine). Another recommended, “It would be better if students could choose the music style and even participate in creating the clips” (Participant 44, Dentistry).

Opportunities and challenges of AI integration in medical education

Students viewed AI-assisted music generation as an innovative educational approach that could enhance creativity and support learning. At the same time, they emphasized the importance of faculty oversight, scientific validation, technical expertise, and adequate preparation time. As one participant observed, “Implementing this approach requires a considerable investment of time beyond regular teaching duties. It also demands adequate skills in using artificial intelligence and digital technologies” (Participant 14, Medicine). In contrast, another participant highlighted its educational potential, stating, “When used appropriately, artificial intelligence can greatly improve learning and understanding. So, I believe it is an excellent educational tool” (Participant 87, Anatomical Sciences).

Overall, the qualitative findings reinforced the quantitative results by providing deeper insight into the educational value of the intervention. Students consistently highlighted the complementary roles of music and visual materials in enhancing engagement, facilitating understanding, supporting knowledge retention, and reducing learning fatigue. They also recognized AI-assisted educational resources as a promising innovation while emphasizing the need for careful instructional design, scientific validation, and continuous refinement. A comprehensive summary of responses to all 11 open-ended questions is provided in Supplementary Table S1.

3.6 Learning outcomes

Students exposed to the AI-assisted music-based educational intervention achieved significantly higher overall final histology examination scores than students receiving conventional instruction (17.41 ± 2.26 vs. 16.10 ± 2.34 , $P < 0.0001$) (Table 3).

When examination performance was stratified by achievement category, the proportion of students attaining Excellent scores (17–20) increased from 46.11% in the historical control group to 68.80% in the intervention group ($P < 0.0001$). No significant between-group differences were observed in the Good, Moderate, or Poor achievement categories (all $P > 0.05$). These findings suggest that the higher overall examination performance was largely driven by the increased proportion of students achieving Excellent scores.

Discussion

The present mixed-methods study evaluated the educational value of integrating AI-assisted music-based educational clips into medical histology teaching. The findings suggest that this approach was

associated with improved student satisfaction, enhanced learner engagement, greater perceived learning, and higher academic performance compared with conventional instruction. Importantly, the educational value observed in this study is unlikely to be attributable to artificial intelligence alone; rather, it appears to result from the integration of generative AI with evidence-based instructional principles, multimedia design, and faculty-guided content development. By combining AI-generated educational music, synchronized histological images, and concise instructional summaries, this study expands current applications of generative AI in medical education beyond commonly investigated domains such as automated feedback, assessment support, and conversational systems.

The improvement in histology examination performance observed among students receiving the intervention is consistent with previous evidence indicating that appropriately designed multimedia learning environments can facilitate knowledge acquisition in medical education. Histology represents a visually demanding discipline in which learners must integrate microscopic images, spatial relationships, and specialized terminology. Previous research has demonstrated that multimedia resources are most effective when verbal and visual information are presented in an integrated manner, allowing learners to construct meaningful mental representations rather than process isolated information (26). Similarly, studies in anatomy and health professions education have reported that technology-enhanced visualization approaches can improve understanding of complex biological structures by supporting spatial reasoning and conceptual integration (27–30). However, previous studies have also emphasized that technology alone does not ensure improved learning outcomes. Poorly designed multimedia materials may increase extraneous cognitive load and interfere with learning processes (31). Therefore, the findings of the present study may be explained by the theory-informed design of the intervention rather than by the use of digital technology alone.

The educational effectiveness of the intervention can be interpreted through Mayer's Cognitive Theory of Multimedia Learning, which proposes that meaningful learning occurs when learners actively select, organize, and integrate information from visual and verbal representations (9, 10, 26). In the present study, histological images, educational lyrics, musical narration, and concise textual explanations were intentionally synchronized to provide complementary sources of information. This multimodal organization may have facilitated connections between microscopic structures and their conceptual descriptions, thereby supporting deeper understanding. Furthermore, the short duration and focused content of the clips may have reduced unnecessary cognitive processing while reinforcing essential concepts after each lecture. These findings are consistent with Cognitive Load Theory, which emphasizes designing instructional materials that minimize extraneous cognitive demands and optimize available cognitive resources for learning (11, 31). Students' qualitative comments further supported this interpretation, as many participants reported that the clips helped them understand difficult concepts, review course material, and retain information more effectively.

The positive learner experiences observed in this study are also consistent with previous literature regarding the educational role of music. Music may influence learning through cognitive and affective mechanisms, including attention regulation, emotional engagement, and memory reinforcement (32). In

medical education, Minhat et al. (2023) reported that integrating music, movement, and visual elements into anatomy education enhanced students' engagement and enjoyment of learning. (33). Similarly, Sheffield and Irons (2021) suggested that educational songs may support understanding and retention by transforming complex scientific information into more memorable formats. Extending these previous findings, the present study demonstrates the potential of AI-generated educational music combined with synchronized histological visualization as a context-specific strategy for supporting engagement and conceptual learning (34).

A distinctive contribution of this study is the integration of generative AI into the development process of educational materials. Previous music-based educational interventions generally required considerable time, specialized expertise, and production resources. In contrast, generative AI platforms may enable educators to rapidly develop customized educational resources aligned with specific learning objectives. This capability may be particularly valuable in medical education, where instructors frequently recognize the importance of multimedia learning but may lack professional skills in content production. Nevertheless, the educational value of AI-generated materials remains dependent on appropriate instructional design, expert review, and continuous quality assurance.

The present findings also contribute to the emerging literature on artificial intelligence in medical education. Previous AI applications have predominantly focused on large language models, automated assessment, personalized feedback, and intelligent tutoring systems. Recent studies have emphasized that successful AI integration requires pedagogical alignment, educator involvement, and responsible implementation rather than technological novelty alone (35–38). In this study, AI-assisted tools supported multiple stages of educational resource development, including language refinement, music generation, and multimedia production, while faculty members maintained responsibility for scientific accuracy and educational appropriateness. These findings support the perspective that generative AI should be considered an augmentation technology that expands educators' capabilities rather than a substitute for human expertise.

The mixed-methods design strengthened the interpretation of the findings by combining objective academic outcomes with students' perceptions and experiences. While examination scores provided evidence regarding potential learning benefits, qualitative responses offered insight into how students experienced the intervention. Participants highlighted increased enjoyment, reduced learning fatigue, improved visualization of microscopic structures, and greater motivation to engage with histology content. Such cognitive and emotional responses are particularly relevant in visually complex disciplines, where maintaining attention and integrating large amounts of information can be challenging (33, 39). Therefore, integrating quantitative and qualitative evaluation approaches provided a more comprehensive understanding of the educational impact of the intervention.

Despite these promising findings, several considerations should guide future implementation of generative AI in medical education. AI-generated resources may contain inaccuracies, inappropriate simplifications, or educational biases if they are not carefully reviewed by subject experts. Furthermore,

developing high-quality AI-assisted materials still requires instructional planning, technological familiarity, and additional effort from educators. Future research should examine long-term knowledge retention, compare different AI-generated instructional formats, and investigate the transferability of this approach across other medical disciplines and educational contexts.

Overall, this study suggests that AI-assisted music-based educational clips represent a feasible, scalable, and theory-informed approach for enhancing histology education. The integration of generative AI with multimedia learning principles provides educators with new opportunities to create engaging and customized learning resources while preserving the essential role of human expertise in educational design, scientific validation, and quality assurance.

Strengths and limitations

This study has several strengths, including its mixed-methods design, integration of quantitative learning outcomes with qualitative learner perspectives, and theory-informed development of the intervention based on multimedia learning and cognitive load principles. The inclusion of a historical control group and the use of a validated satisfaction questionnaire further strengthened the evaluation of the educational intervention.

However, several limitations should be acknowledged. The single-center design may restrict generalizability. The use of a historical control group may have introduced potential cohort-related confounding factors. In addition, the study evaluated immediate academic performance and did not assess long-term knowledge retention or transfer of learning. Objective measures of cognitive load and engagement were also not included. Finally, although generative AI facilitated content creation, expert faculty involvement remained essential for ensuring scientific accuracy and educational appropriateness. Future research should investigate the long-term impact of AI-assisted educational resources and their effectiveness across diverse medical education settings.

Conclusion

This study suggests that AI-assisted music-based educational clips represent a feasible and theory-informed approach for enhancing medical histology education. The intervention was associated with improved student satisfaction, engagement, perceived learning, and academic performance compared with conventional instruction. The findings highlight that the educational value of generative AI depends not only on technological capabilities but also on appropriate instructional design, educational theory, and faculty oversight. Generative AI may serve as a supportive tool that enables educators to develop customized and scalable learning resources while maintaining scientific and pedagogical quality. Further studies with larger, multicenter samples and longitudinal follow-up are needed to evaluate the long-term effectiveness and broader applicability of this approach.

Abbreviations

- AI
Artificial Intelligence
- ANOVA
Analysis of Variance
- CGPA
Cumulative Grade Point Average
- GPA
Grade Point Average
- SD
Standard Deviation
- SEM
Standard Error of the Mean
- SSIM_sQ
Short Student Satisfaction with Innovative Teaching Methods Questionnaire

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Babol University of Medical Sciences, Babol, Iran (Approval No. IR.MUBABOL.HRI.REC.1405.052). All procedures involving human participants were conducted in accordance with the ethical standards of the institutional research committee and the principles of the Declaration of Helsinki and its subsequent amendments. Participation in the study was voluntary. Before data collection, participants were informed about the study objectives, the voluntary nature of participation, and the confidentiality of their responses.

Consent for publication

Not applicable.

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

ZB conceptualized and designed the study.

ZB and MG acquired the data. SR analyzed the data. MG and AM drafted the manuscript. ZB critically revised the manuscript. All authors read and approved the final manuscript.

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AI-assisted language tool (ChatGPT) was used solely to improve the clarity and readability of the manuscript. The authors critically reviewed, edited, and verified all AI-assisted outputs and take full responsibility for the accuracy, originality, and integrity of the manuscript. No AI tools were used in the study conception, study design, data collection, data analysis, interpretation of the results, or the formulation of the study conclusions.

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Table 3

Table 3 is available in the Supplementary Files section.

Figures

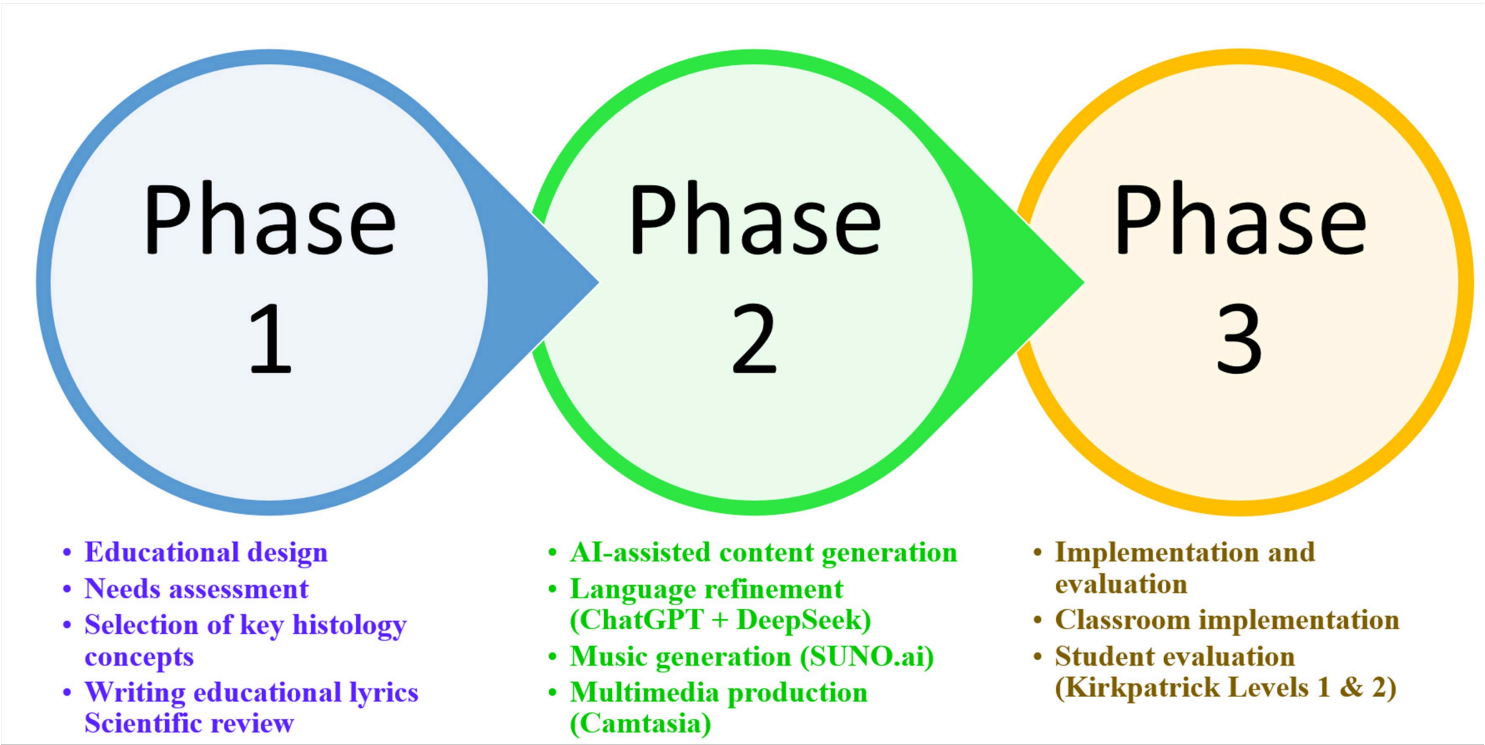


Figure 1

Development and implementation workflow of the AI-assisted music-based educational intervention. The workflow comprised three phases: educational design, AI-assisted multimedia development, and classroom implementation with evaluation based on the first two levels of the Kirkpatrick Evaluation Model

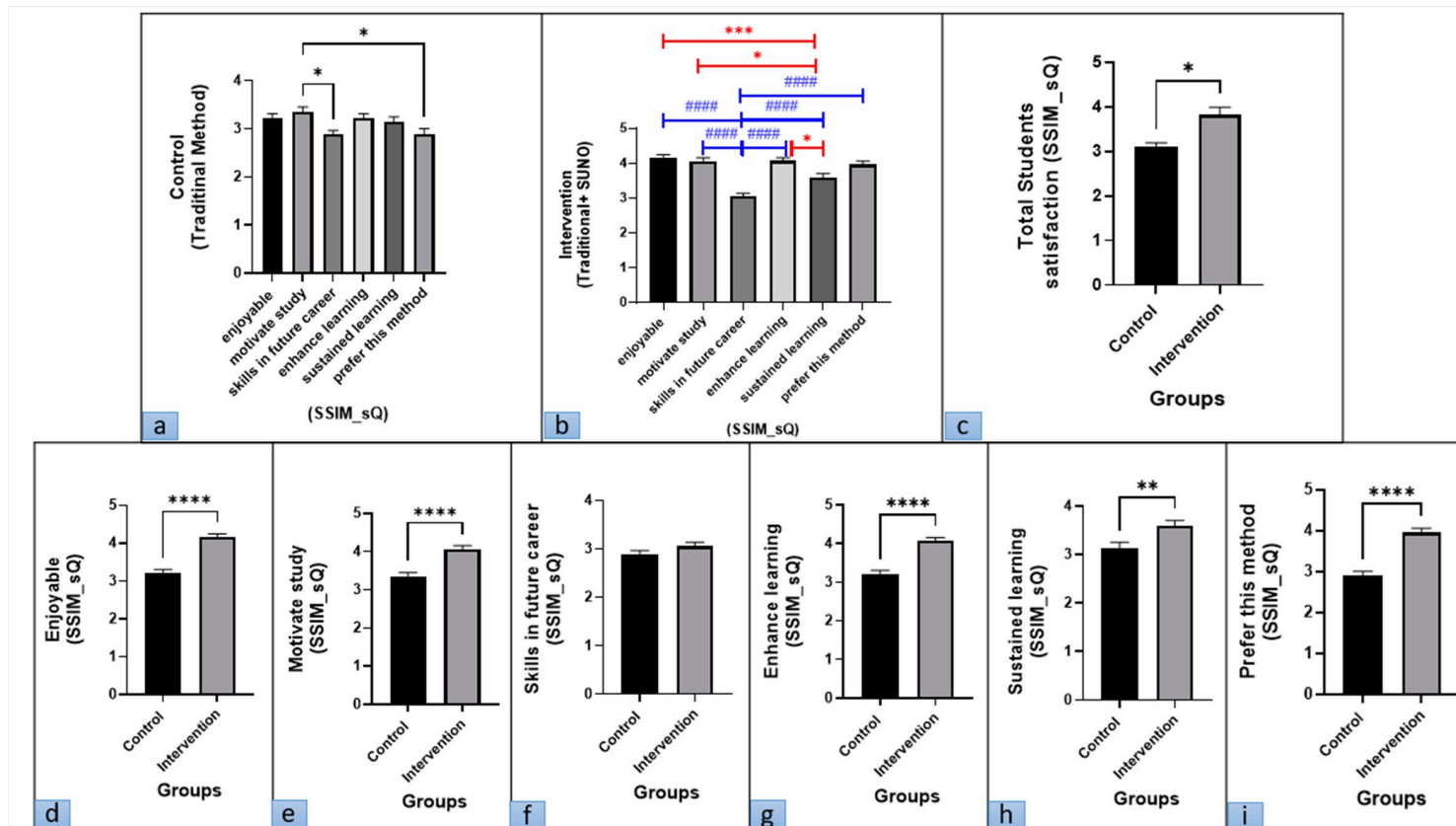


Figure 2

Student satisfaction (SSIM_sQ) following conventional instruction and the AI-assisted music-based educational intervention.

(A) Conventional instruction group. (B) Intervention group. (C) Overall satisfaction score. (D–I) Between-group comparisons of enjoyment of learning, motivation to study, perceived contribution to future professional skills, enhancement of learning, long-term knowledge retention, and preference for the educational approach. Data are presented as mean $\pm$ SEM. $P < 0.05$, $P < 0.01$, $P < 0.001$, $P < 0.0001$, $####P < 0.0001$.

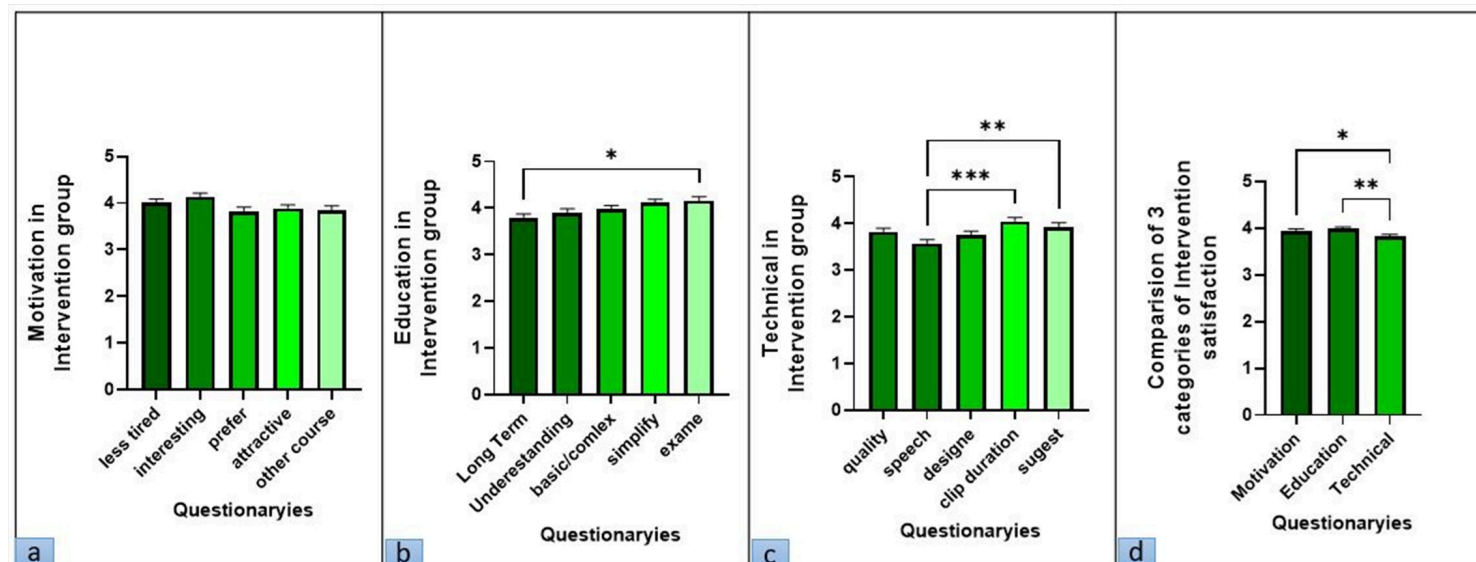


Figure 3

Students' evaluation of the AI-assisted music-based educational intervention.

Results of the intervention-specific questionnaire completed by students in the intervention group. (A) Motivational outcomes, including reduced learning fatigue, increased interest in histology, preference for the intervention, perceived attractiveness of the course, and willingness to use similar educational resources in other medical courses. (B) Perceived educational effectiveness, including long-term knowledge retention, improved understanding of histology, learning of basic and complex histological concepts, simplification of difficult concepts, and usefulness for examination review. (C) Technical and instructional quality, including audiovisual quality, speech quality, visual design, clip duration, and willingness to recommend the educational clips for future use. (D) Comparison of the three questionnaire domains. Data are presented as mean $\pm$ SEM. $P < 0.05$, $P < 0.01$, $P < 0.001$.

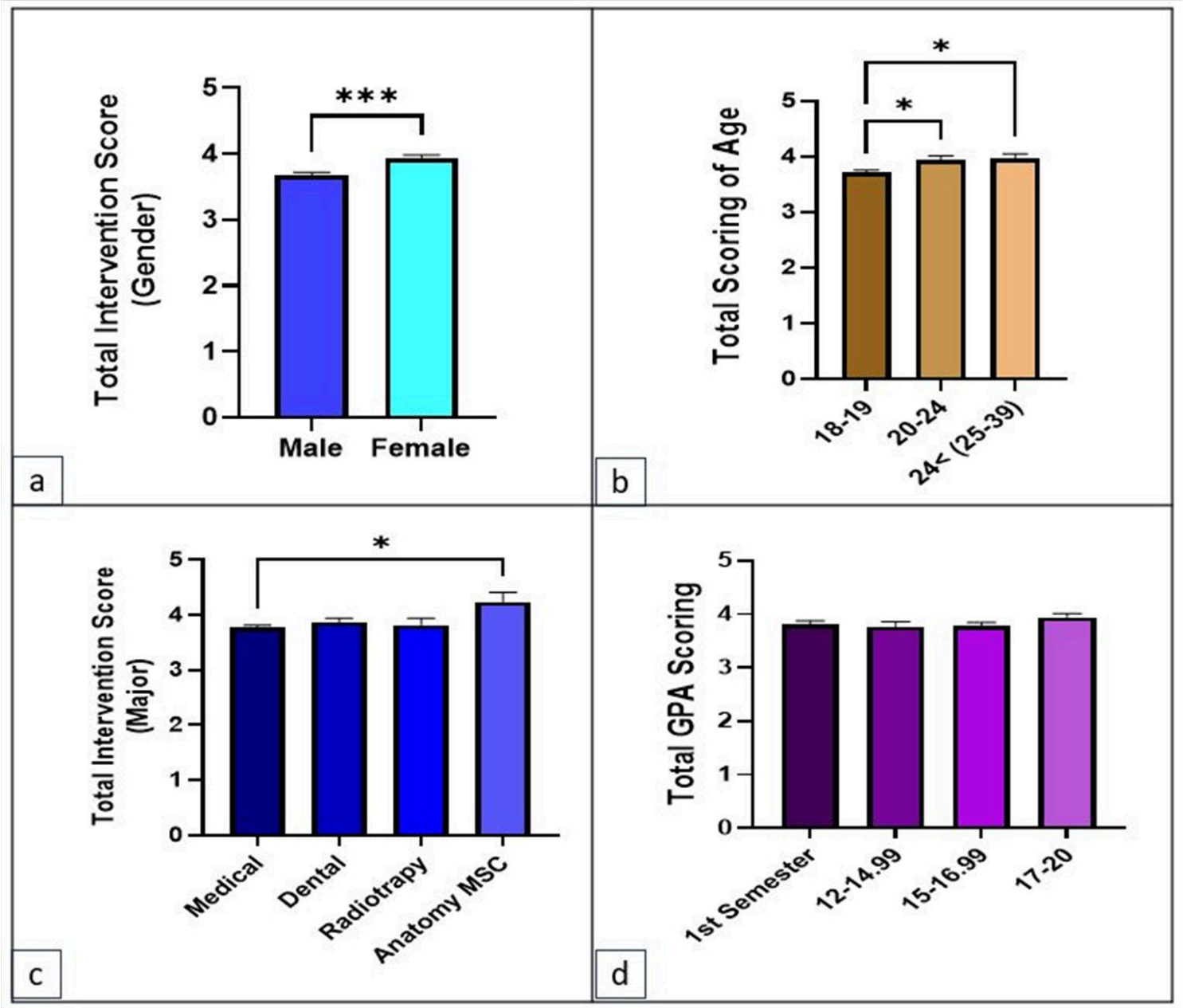


Figure 4

Subgroup analysis of students' overall evaluation of the AI-assisted music-based educational intervention.

Overall scores from the intervention-specific questionnaire were compared according to (A) gender, (B) age group, (C) academic discipline, and (D) grade point average (GPA). Data are presented as **mean $\pm$ SEM**. $P < 0.05$; $P < 0.001$.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementary.docx](#)
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