Vocal Hero: A Rhythm-Based Educational Minigame for Teaching Vocal Cord Function

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***Abstract.* *Introduction*:** *Teaching dynamic physiological processes like vocal cord function is challenging with static representations.* ***Objective*:** *This work presents the design and development of an educational minigame focused on the dynamic behavior of the vocal folds, commonly known as vocal cords, and associated laryngeal structures during phonation.* ***Methodology*:** *The game combines a narrative introduction with rhythm-based mechanics. Players respond to time-synchronized visual stimuli while a real-time 3D vocal cord model provides immediate visual feedback on vibration patterns. The MEEGA+ instrument was used to evaluate user experience and perceived usability with 29 participants.* ***Results*:** *MEEGA+ results indicated high acceptance of the game across multiple dimensions (overall mean 3.73/5), with top scores in Relevance (4.83) and Perceived Learning (4.81). The game achieved a good perceived quality score (IRT = 45.53), suggesting positive perceived educational potential based on participants' self-assessment.*
Keywords *Serious Games, Anatomy Education, Vocal Cords, Game-Based Learning, Educational Technology.*

1. Introduction

Human anatomy serves as a fundamental basis for education in health and biomedical fields. In recent years, this discipline has been influenced by the incorporation of educational technologies and by changes in the student profile, which is increasingly familiar with interactive digital environments [Henssen et al. 2020, Stiver et al. 2025]. As a result, educators have sought to integrate technological resources into their pedagogical strategies, including interactive digital tools that can complement both theoretical instruction and laboratory-based learning experiences [Adnan et al. 2024, Cullinane et al. 2023].

An additional aspect concerns the limitations of conventional anatomy teaching, traditionally grounded in the use of cadavers. The literature highlights barriers related to the availability of these materials, the associated costs, and the inherent difficulties in understanding three-dimensional structures through traditional approaches [Kurul et al. 2020, Ma et al. 2016]. In this scenario, there is a growing demand for more dynamic and accessible pedagogical strategies. In this regard, technological resources such as virtual reality, augmented reality, and educational digital games have increasingly been integrated into teaching across health-related programs [Bork et al. 2021, Du et al. 2020, Yow 2022].

Among these strategies, serious games — defined as games designed with a primary purpose other than pure entertainment, such as education or training [Zyda 2005] - show considerable potential for promoting engagement and active learning [Ricciardi e de Paolis 2014, Zhonggen 2019]. However, challenges remain regarding the functional representation of anatomical structures and the assessment of the educational impact of these tools. In the specific case of the vocal cords, understanding their function requires knowledge of their anatomy and insight into their dynamic behavior during sound production.

In light of this, the present study introduces a serious game focused on understanding the functioning of the vocal cords during phonation. The game addresses the dynamic behavior of key laryngeal structures, including the vocal folds, arytenoid cartilages, and cricothyroid muscle, which are involved in controlling pitch and voice production. The player interacts with a rhythm-based system, being challenged to respond to patterns that represent variations in vocal cord vibration in order to produce different sound frequencies. The experience is supported by contextualized dialogues that explain the involved structures and their functions.

The evaluation of the proposal was carried out through a pilot study with lay participants, in which we applied the MEEGA+ questionnaire to assess players' demographics, perceived usability, and user experience [Petri e von Wangenheim 2018][1]. The results indicated that participants perceived a better understanding of the role of the vocal cords in sound production while enjoying the game and finding it usable, suggesting that, based on participants' self-assessment, a narrative- and interaction-based approach may positively influence their perceived understanding of complex concepts. It is important to note that these findings reflect perceived learning rather than measured learning gains, as the study did not employ pre- and post-tests to assess actual knowledge acquisition.

As a contribution, this study proposes an innovative strategy for teaching functional anatomy, integrating game mechanics with educational content in an accessible way. Furthermore, it seeks to address the following research question: (RQ) What is the users' perception of the proposed game?

[1]In accordance with Article 1 of CNS Resolution No. 510 of 2016 and Article 26 of CNS Resolution No. 674 of 2022, this research does not require approval from the Ethics Committee, particularly because it involves the collection of anonymized opinions.

2. Vocal Folds

The vocal folds are paired mucosal structures located within the larynx. During phonation, airflow from the lungs interacts with the elastic tissue of the adducted folds, producing vibration and the fundamental sound of the voice. Pitch is regulated through changes in vocal fold length, tension, thickness, and effective vibrating mass. The cricothyroid muscle increases vocal fold length and tension by tilting the thyroid cartilage relative to the cricoid, thereby raising pitch [Titze 1994], whereas the thyroarytenoid muscle modifies vocal fold thickness, stiffness, and vibratory behavior. Movements of the arytenoid cartilages adduct or abduct the vocal folds, controlling glottal closure, airflow, and phonation onset. Efficient phonation also depends on the mucosal wave, a wave-like movement of the flexible vocal fold covering that supports vibration [Hirano 1974].

The game addresses these relationships through a simplified educational representation. Through rhythm-based mechanics, players interact with changes in pitch and glottal configuration, while a real-time 3D model provides visual feedback on vocal fold length, tension, and position during sound production.

3. Related Works

The use of game elements in education encompasses both gamification — the application of game mechanics in non-game contexts — and serious games, which are complete games designed with a primary educational purpose. Studies such as the one by [Alves 2014] discuss gamification as a tool to assist teaching across various areas, while serious games have been explored as interactive environments for active learning. In health education, both approaches have been widely used to make learning more interactive and effective, with key gamification elements including clear instructional objectives, game rules, rapid feedback, fairness, and scoring systems, as presented by [Wang et al. 2024].

[Buajeeb et al. 2024] developed a simulation-based serious game aimed at teaching diagnosis and treatment planning of oral lesions. The study involved 75 dentistry students and showed that the use of the game significantly improved participants' performance, achieving results comparable to those obtained through traditional lectures. However, the application is situated within a specific clinical context, focuses on diagnostic decision-making rather than functional anatomy, and targets students with prior knowledge, which limits its use for broader audiences.

[Castellano et al. 2024] presented a digital platform for teaching human anatomy based on interactive challenges and intelligent recommendation systems. Evaluated with 131 students, the tool demonstrated a positive impact on academic performance, highlighting the potential of interactive technologies for teaching complex content. Nevertheless, the approach emphasizes question-solving and adaptive content delivery, devoting less attention to the dynamic, real-time representation of physiological processes — such as the vibratory behavior of vocal folds during phonation.

[Regattieri et al. 2025] applied gamification strategies to create a quiz-based game in which students answered questions about anatomical cases or structures. Correct answers allowed their avatars to defeat monsters, earning currency to customize characters. While effective for reinforcing static anatomical knowledge through quizzes, the proposal does not simulate physiological function or provide real-time 3D visual feedback of dynamic anatomical events.

In this context, the present work distinguishes itself by proposing a serious game centered on the functional anatomy of vocal cord phonation. The game explicitly addresses the dynamic roles of specific laryngeal structures — including the vocal folds, arytenoid cartilages, and cricothyroid muscle — in controlling pitch and voice production. Rather than relying on quizzes or static images, the experience places the player in direct interaction with sound production control through rhythm-based mechanics, exploring the relationship between airflow, vocal fold vibration, and frequency modulation. A real-time 3D model provides immediate visual feedback of the vibratory patterns, enabling users to observe, in a practical and contextualized way, how different pitches are produced. This approach promotes learning that goes beyond memorization by integrating functional and perceptual aspects of anatomy. Furthermore, the user experience is systematically evaluated using the validated MEEGA+ instrument, providing rigorous data on perceived usability and learning.

4. Game Design

4.1. Game Structure and Flow

The minigame was structured into three main stages: theoretical contextualization, practical interaction, and final feedback. Initially, the player accesses the main menu and is then directed to a sequence of narrative dialogues, developed with the support of an anatomy education specialist. These dialogues introduce the vocal folds, arytenoid cartilages, and cricothyroid muscle, explaining their coordinated roles in glottal closure, pitch control, and phonation (Figure 1). The content was presented in Brazilian Portuguese, the native language of the initial test participants.

Figure 1. Dialogue interface presenting educational content about vocal cords prior to the gameplay.

During this stage, fundamental concepts are presented, including the anatomical location of the vocal folds, the interaction between airflow and vocal fold vibration, and the role of muscle-driven changes in vocal fold tension in pitch variation. This content provides an initial conceptual foundation, particularly for users with no prior knowledge.

After the introduction, the player proceeds to the main minigame, where rhythm-based controls simulate adjustments in vocal fold tension and glottal configuration. The

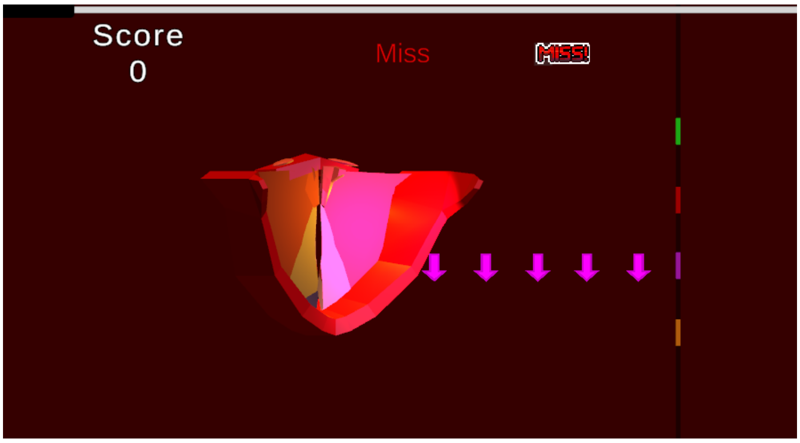

Figure 2. Gameplay interface with rhythm-based visual stimuli and real-time 3D vocal cord model.

player responds to time-synchronized stimuli, and a real-time 3D model of the larynx displays the corresponding anatomical movements — stretching of the vocal folds, changes in arytenoid position — thereby reinforcing the previously introduced concepts. At the end of the activity, a feedback screen presents a qualitative performance evaluation (e.g., “good” or “very good”) along with accuracy metrics, allowing the player to reflect on their performance.

4.2. Game Mechanics

The game is based on rhythm mechanics, requiring players to respond to sequential visual cues with precise timing. Each arrow corresponds to a simplified phonatory response. The inputs are associated with different configurations of vocal fold tension, length, and thickness, representing variations between higher- and lower-pitched sounds. The model also demonstrates vocal fold adduction and abduction through movements of the arytenoid cartilages, representing glottal closure during phonation and glottal opening during breathing or interruption of phonation. A 3D larynx model provides immediate visual feedback by animating these anatomical changes.

Player performance is continuously evaluated through “Perfect”, “Good”, and “Miss” feedback, while a combo system rewards consecutive successful actions. Rather than penalizing mistakes with interruptions or failure states, the game encourages continuous practice, treating errors as part of the learning process [Gauthier e Jenkinson 2018].

4.3. Anatomical Representation and Feedback

As the central learning element, the game features a three-dimensional model of the vocal folds displayed in real time during gameplay. This model responds directly to the player’s actions, functioning as a visual feedback system for the phonation process (Figure 2). High-pitched notes are triggered by green (left) and red (up) inputs, causing the model to show increased vocal fold length and tension associated with cricothyroid contraction. Arytenoid adduction is maintained to provide the glottal closure required for phonation. Low-pitched notes, mapped to pink (down) and orange (right), are represented, in a simplified manner, by relatively reduced longitudinal tension and a shorter and thicker vocal fold configuration, associated with reduced cricothyroid action and the contribution of the thyroarytenoid muscle. Glottal closure is maintained during this process to support phonation. Arytenoid abduction represents glottal opening and interruption of phonation rather than low-pitch production. The use of three-dimensional representations has been shown to support the understanding of complex anatomical structures and their dynamic behavior, particularly in educational contexts [Al Habsi et al. 2025, Rosado 2025].

When the player performs the correct input, the model presents a simplified visual representation of the expected vocal fold position and vibratory behavior. Incorrect inputs generate a contrasting visual response, indicating a deviation from the target anatomical configuration without intending to reproduce a complete abnormal physiological condition. In addition to visual feedback, the game also provides auditory cues to indicate player performance, with correct inputs reinforced by positive sound effects and errors indicated by distinct audio signals. Immediate and multimodal feedback plays a key role in serious games, supporting user engagement and allowing players to monitor their performance without interrupting the interaction flow [Almo et al. 2023, Nadolski e Hummel 2017].

By establishing a direct relationship between player interaction and the simulated biological response, the system enables the visualization of a process that is not easily observable in real life. As a result, abstract concepts such as vibration and frequency modulation become more accessible through interactive experience.

4.4. Pedagogical Strategy

The game was designed as a complementary tool for anatomy education, supporting traditional instruction through interactive learning. Its pedagogical approach is grounded in constructivist principles, whereby knowledge is built through experimentation, interaction, and the association between player actions and immediate visual feedback [Kaimara 2023]. The absence of punitive mechanics encourages exploration in a safe learning environment.

To sustain engagement, the game balances challenge and player ability, following the concept of flow [Admiraal et al. 2011, Prasad et al. 2020]. The combination of narrative, rhythm-based gameplay, and real-time 3D anatomical visualization helps players relate the behavior of the vocal folds, arytenoid cartilages, cricothyroid muscle, and thyroarytenoid muscle to sound production, supporting perceived understanding through meaningful interaction.

5. Methods

5.1. Study Design

This study adopted a quantitative approach to evaluate the perceived educational value and user experience of the proposed game. Data were collected entirely online using Google Forms and consisted of a demographic questionnaire followed by the MEEGA+ instrument [Petri e von Wangenheim 2018]. After providing informed consent, participants completed the demographic questionnaire, downloaded and played the game on their PCs through a link provided in the form, and subsequently answered the MEEGA+ questionnaire.

Demographic data included age, gender, educational background, state of residence, income range, and frequency of engagement with digital and non-digital games. The MEEGA+ instrument evaluates usability and player experience through 33 Likert-scale items covering the dimensions of Aesthetics, Learnability, Operability, Accessibility, Confidence, Challenge, Satisfaction, Social Interaction, Fun, Focused Attention, Relevance, and Perceived Learning. The complete questionnaire is available in the supplementary material (Section A).

5.2. Participants

A total of 31 participants were recruited online. Two were excluded after failing an attention check question included in both the pre- and post-test questionnaires, following established recommendations [Pei et al. 2020, Kung et al. 2018, Silber et al. 2022]. Therefore, the final sample consisted of 29 participants.

Most participants identified as cisgender men (82.76%), while 13.79% identified as cisgender women and one participant preferred not to disclose their gender. Participants were between 19 and 60 years old (M = 26.1, SD = 9.7), and most reported incomplete higher education (62.07%).

All participants were from Brazil, predominantly from the state of São Paulo (82.76%). The most common income range was 5 to 10 minimum wages (34.48%), followed by 1 to 3 minimum wages (27.59%).

Regarding gaming habits, most participants reported playing digital games daily or weekly (75.86%), whereas non-digital games were played only rarely by most respondents (62.07%).

5.3. Data Analysis

The collected data were analyzed using descriptive statistics as suggested by MEEGA+ authors [Petri e von Wangenheim 2018]. For user experience evaluation, MEEGA+ responses were analyzed descriptively for each dimension, where higher mean scores indicate a better perceived experience regarding usability, engagement, enjoyment, and perceived learning. All analyses were performed using an R language script. Following the MEEGA+ guidelines, we report the distribution of answers per question, their medians, and the Item Response Theory (IRT) quality score, which summarizes perceived overall quality based on the item parameters[2].

6. Results

A total of 29 valid participants completed the study. Addressing our research question (RQ) regarding users' perception of the proposed game, the MEEGA+ results indicated a positive overall evaluation. The overall mean score was 0.73 on the original MEEGA+ scale (-2 to +2), corresponding to 3.73 on the 5-point Likert scale. Internal consistency was high, with Cronbach's Alpha = 0.90 and McDonald's Omega Total = 0.94.

Among the evaluated dimensions, Learnability (4.70), Operability (4.52), Accessibility (4.46), and Aesthetics (3.94) received the highest usability scores, indicating that participants generally perceived the game as easy to learn, intuitive, accessible, and

[2] `https://www.ufsm.br/grupos/gptec/paginas/portfolio/meega`

visually adequate. Social Interaction obtained the lowest mean score (2.00), which is expected for a single-player experience. Figure 3 summarizes the average scores for all evaluated dimensions.

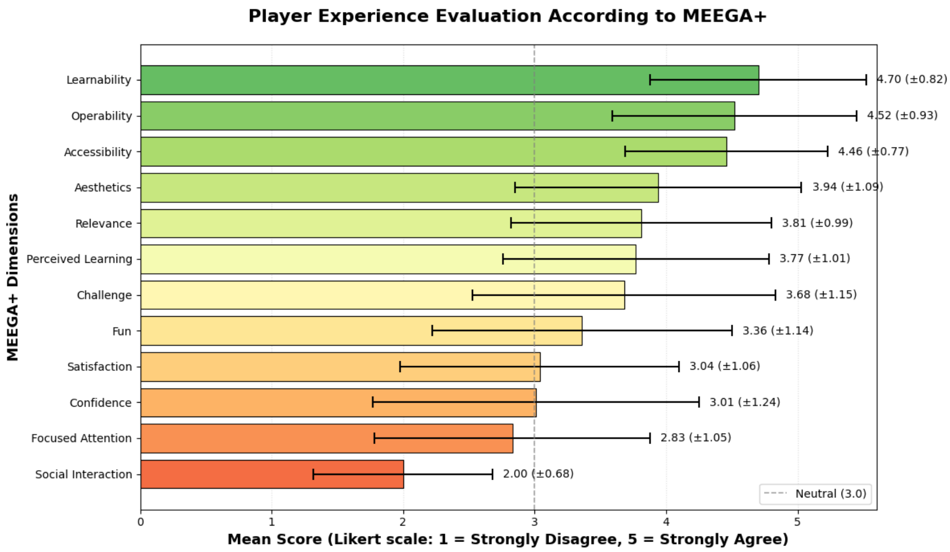

Figure 3. MEEGA+ evaluation of player experience across all assessed dimensions.

Regarding the Usability factor (Figure 4), most responses were positive (Agree or Strongly Agree). All items obtained a median of 2 (Strongly Agree), except Q1 ("The game design is attractive"), which obtained a median of 1 (Agree), indicating an overall positive usability evaluation.

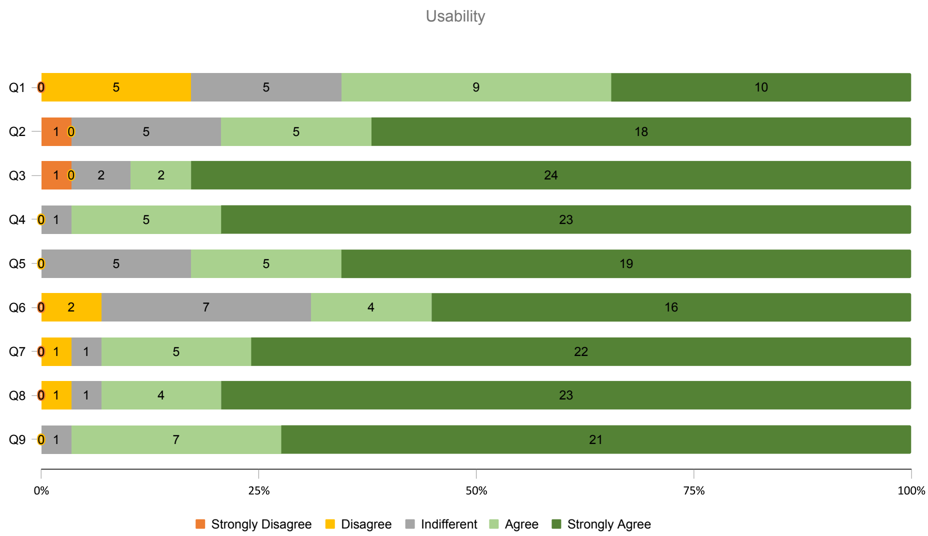

Figure 4. Frequency distribution of responses for the Usability factor.

For the Player Experience factor (Figure 5), most items also received predominantly positive responses. However, neutral medians (0) were observed for Q13 (monotony), Q22 (smiling during gameplay), Q23–Q25 (focused attention), and

Q26 (relevance to personal interests). As expected for a single-player game, the Social Interaction items Q18 and Q19 obtained median values of -2, while Q20 obtained a median of -1.

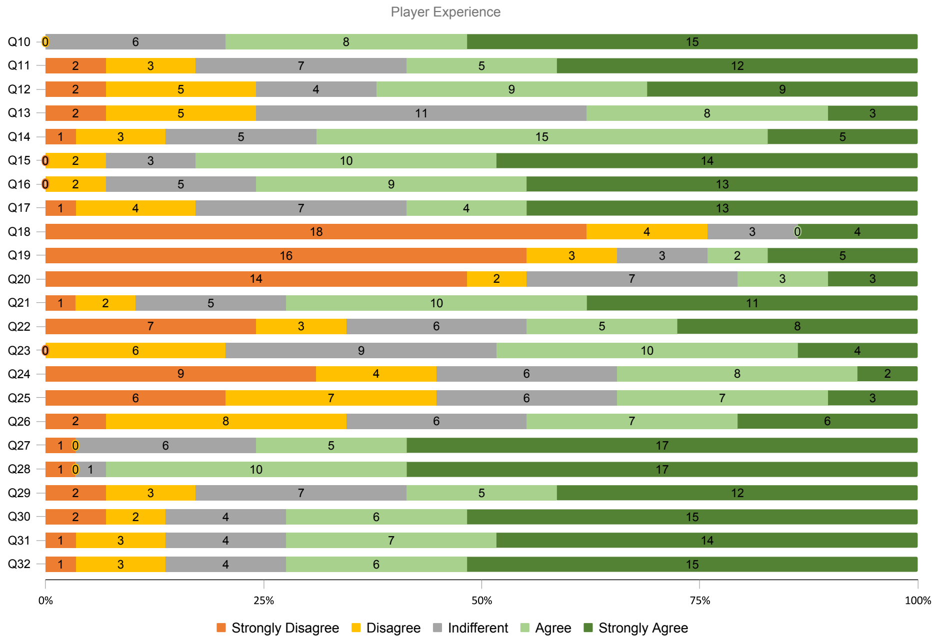

Figure 5. Frequency distribution of responses for the Player Experience factor.

Following the MEEGA+ Item Response Theory (IRT) analysis, the game achieved a quality score of 45.53, exceeding the minimum threshold for good quality (42.5) but remaining below the excellent quality threshold (65). Therefore, according to the MEEGA+ classification, the game is considered to have good quality [Petri e von Wangenheim 2018].

Participants also provided optional written comments. Overall, the feedback was positive, with the most frequent suggestions involving additional difficulty levels, more precise feedback on note timing, and improvements to the user interface.

7. Discussion and Implications

The results indicate that participants perceived "Vocal Hero" positively in terms of usability, user experience, and perceived learning. High scores for Learnability, Operability, Accessibility, and Perceived Learning suggest that the rhythm-based mechanics and anatomical feedback provided an accessible experience while supporting participants' understanding of the proposed content. The high internal consistency of the MEEGA+ responses further strengthens the reliability of these findings.

However, neutral ratings for monotony (Q13) and focused attention (Q23–Q25), together with participants' written feedback, indicate that the current gameplay may become repetitive during longer sessions. Although the game achieved a good IRT quality classification, future iterations should introduce greater gameplay variety, progressive difficulty, and additional anatomical scenarios to improve long-term engagement.

Importantly, the present study evaluated perceived rather than objective learning. Although participants reported high Perceived Learning scores, no pre- and post-test was conducted to measure knowledge acquisition. Therefore, the educational effectiveness of the proposed approach should be investigated through controlled studies involving objective assessments and health sciences students.

From an educational perspective, the proposed game complements traditional anatomy teaching by enabling learners to visualize dynamic physiological processes that are difficult to observe using static materials. More broadly, the results suggest that integrating meaningful gameplay mechanics with real-time anatomical feedback can positively support users' perceived learning.

7.1. Threats to Validity and Limitations

The sample was predominantly young, highly educated male gamers from São Paulo, which limits generalizability to broader populations, including health sciences students. Self-report bias, lack of objective learning measures, and short exposure (a single session) are additional limitations. Consequently, the results reflect perceived learning rather than actual knowledge gains, and the neutral ratings on monotony and focused attention may partly stem from the limited gameplay variety available in a brief interaction. The game simplifies vocal cord physiology, which may limit depth for advanced learners. Despite these limitations, the use of a validated instrument, attention checks, and IRT analysis provides a rigorous evaluation of user experience and perceived quality.

8. Conclusion

This work presented "Vocal Hero," a rhythm-based educational minigame designed to teach the functional relationships among the vocal folds, arytenoid cartilages, and cricothyroid muscle during phonation. Evaluation with 29 participants using the MEEGA+ instrument indicated positive user perception, with high scores for Relevance and Perceived Learning, and an overall IRT classification of good quality. Neutral ratings for monotony and focused attention suggest opportunities to improve long-term engagement through greater gameplay variety.

Overall, the results suggest that "Vocal Hero" is a promising complementary tool for anatomy education. However, the present findings reflect perceived learning rather than objective learning gains. Future work includes expanding gameplay variety, conducting controlled studies with pre- and post-tests involving health sciences students, and exploring optional multiplayer features. The game materials are available in the OSF repository.

Declaration of Generative AI and AI-assisted technologies

We used LLMs such as DeepSeek and ChatGPT to improve the article's overall quality. We take full responsibility for all content produced with AI assistance.

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A. Supplementary Material

Supplementary material, such as the questionnaire, the dataset, scripts, game screenshots, gameplay videos, and complementary graphics, can be found at our OSF repository [3].

[3]https://osf.io/4ynbt/overview?view_only=b3fe854ec2c041968722d19ffc250d24