

MetaNODES: A Virtual Reality-Based Approach to Intelligent Neuro-Ophthalmology Education

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Abstract—Virtual Reality (VR), as the technological cornerstone of the metaverse, has attracted much attention in the digital transformation of medical education. In the medical education of ophthalmology, teaching neuro-ophthalmologic disease diagnosis is considered crucial but challenging due to its complex principles of neurology and anatomy. Leveraging its high interactivity and immersion, the VR can turn the conventional and difficult learning process to gain professional neuro-ophthalmologic knowledge into an intuitive experience with explainable physiological and anatomical features. Inspired by this idea, this paper presented the Metaverse Neuro-Ophthalmologic Disorder Education System (MetaNODES), a VR-based intelligent pedagogical solution for neuro-ophthalmology education deployed on Meta's Oculus Quest 2. The Unity game engine was adopted to replicate the realistic clinical diagnostic process of various neuro-ophthalmologic disorders. Under the guidance of professional ophthalmology experts, our team designed a quantitative visualization model for sophisticated gaze direction, face morph, and the body motion control of a VR patient to reproduce the real-time symptom responses based on the user interface (UI) operation and motion state change of the Quest controller. Dedicated scenario modes were carefully designed and implemented for the precision of the clinical manifestations as well as the hardware characteristics of the VR device. The evaluation conducted on a group of students revealed that the MetaNODES system can assist them to better appreciate the apparent symptoms and comprehending the underlying mechanisms with a deeper engagement. To the best of our knowledge, the MetaNODES system is a pioneering effort to integrate VR into neuro-ophthalmology education. It initiated a fundamental framework of leveraging common VR devices to deploy Metaverse to ophthalmology education in online learning environments.

Index Terms—virtual reality, metaverse, medical education, neuro-ophthalmology, gamified learning, Oculus Quest, Unity game engine

I. INTRODUCTION AND RELATED WORKS

Pedagogical design and organisation of ophthalmology have been considered difficult tasks in medical education due to

a lack of student motivation and engagement [1]. An essential lesson for medical students studying ophthalmology is appropriately diagnosing neuro-ophthalmologic disorders and comprehending the underlying neurological and muscular pathological causes. The ocular motility examination is a necessary diagnostic procedure. During the test, the ophthalmologist asks the patient to follow a target with their eyes while keeping their head still. The examiner observes the possible abnormalities to determine the patient's disorder. Nevertheless, clinical symptoms related to neuro-ophthalmology can be complex and varied since they involve the coordination of multiple extraocular muscles and the nerves manipulating them [2] [3]. For instance, patients with third cranial nerve palsy, a typical neuro-ophthalmologic disorder, have great difficulty in looking upward (elevation) and looking inward (adduction) with droopy eyelids (ptosis) and dilated pupils. Textbooks and other traditional teaching approaches are not always able to adequately elaborate on the symptoms and principles of various neuro-ophthalmologic disorders. Furthermore, the unidirectional transmission of medical knowledge can be tedious, reducing students' interest and engagement.

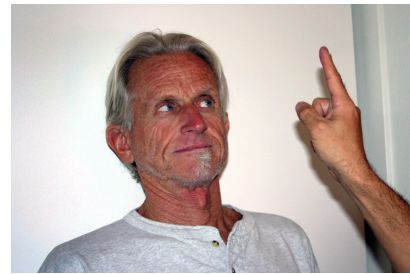


Fig. 1: Ocular motility examination (adapted from [4]).

Over the past decade, researchers and educators have focused on applying emerging human-computer interaction

(HCI) technologies to facilitate complex medical training processes. With its advantage of omni-vision, VR has been proven to boost students' learning motivation and achievement significantly, creating immersive scenarios beyond real-world teaching space limitation [5]. Particularly for medical students, VR can provide unique educational experiences of otherwise rarely accessible real-world clinical diagnosis cases [6] [7]. Numerous study cases have manifested the practicality of using VR Head-mounted display (HMD) devices in medical training, especially in teaching anatomy and simulated surgery [8] [9]. Nevertheless, studies and applications of VR HMD devices in neuro-ophthalmology clinical diagnosis simulation are seldom identified in literature surveys of VR-enhanced ophthalmology education [11] [12].

To fill the gap, our team proposed the MetaNODES system to utilise VR HMD devices as a potent accelerator for immersive neuro-ophthalmology learning. The system performs realistic reproduction of diagnostic scenarios with a VR patient character, allowing students to study through interactive practice. Students can easily interact with the 3D UI elements to alter the VR patient's disorder type and related expression setting [13]. The student's hand position and motion, as measured by the Quest controller sensors, steer the VR patient's visual direction [14]. Additionally, to encourage students to participate in active learning, the system also features a mission game mode that mimics diagnostic tasks under preset or random conditions [15] [16]. More potential of the MetaNODES system can be discovered through deployment in the open online learning environment to achieve decentralised interactive ophthalmology education [17].

II. METHODOLOGY AND SYSTEM IMPLEMENTATION

A. System Overview

The use of metaverse in medical education is becoming progressively feasible thanks to the general availability of affordable VR HMD devices and 3D game engines. The MetaNODES system has embraced the Oculus Quest 2, a VR HMD device developed by Meta. Its superior cost-effectiveness and mature development framework makes it ideal for extensive application in interactive medical education. In addition, the Oculus Quest 2 outperforms in accurate motion tracking compared to other VR HMD devices in the same price range [18] [19]. The software platform used to create scenes with the UI elements and control the symptoms and actions of the VR patient across multiple scenarios mode is the Unity game engine. Its programmable functions precisely control the VR patient's ocular symptoms and head actions [20]. Precise coordination between the hardware and software guarantees medical rigour in ophthalmology education.

Fig. 2 demonstrates the overall architecture and information flow of the system. The student manipulates the position and motion of the primary controller to instruct the VR patient to gaze in the desired direction. Via the projected raycast (laser beam emitted by Oculus Quest controllers), the secondary controller is utilised to interact with the 3D UI elements. Three unique scenario modes are intended to demonstrate particular

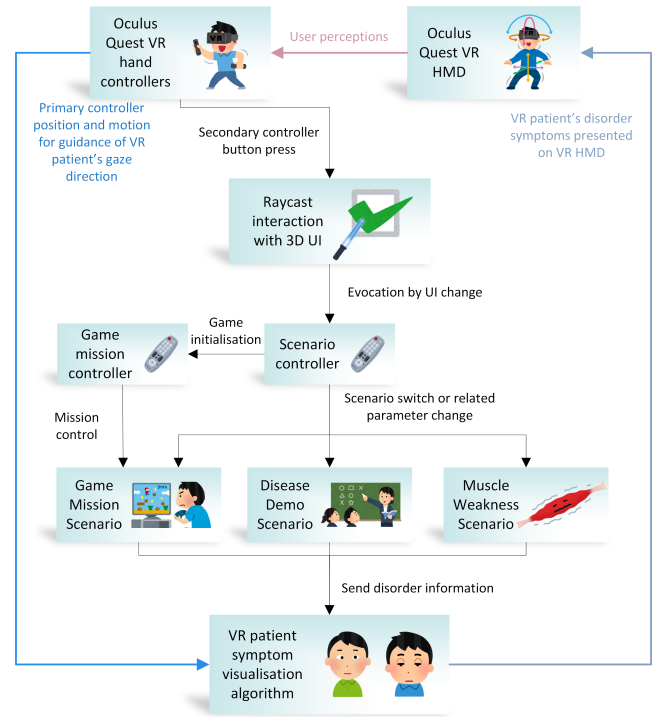


Fig. 2: System architecture of MetaNODES.

diseases, show the weakening effect of different extraocular muscles, and conduct diagnostic mission games, respectively. The VR HMD displays the symptoms of the VR patient, giving the student six degrees of freedom (DOF) to observe.

B. Ocular Movement Visualisation

An accurate representation of normal eye movement range is essential to reproducing realistic symptoms. The normal people's extreme gaze angle (maximum angles of eyeball rotation) varies with its direction [21]. Authoritative research studies regarding ocular motility have conducted measurements of the extreme gaze angles in cardinal positions [22] [23]. Referring to previous measurement results and professional ophthalmologists' opinions, a quantitative model is proposed to visualise the relationship between the student's primary hand position and the VR patient's gaze direction. Two symmetrical spatial boundaries with overlapping space are created by fitting the extreme gaze angles on conic surfaces in different quadrants for both eyes. The VR patient's sight line follows the student's index fingertip on the primary controller within the spatial boundary. Otherwise, the VR patient's sight line tries to capture the student's index fingertip with utmost effort. Fig.3 demonstrates the difference in ocular movement response of the VR patient when the student's guidance is inside and outside the spatial boundary.

C. VR patient and 3D UI design

A user-centred scene design with attractive content and easy-to-use UI can significantly enhance students' acceptance and engagement in VR medical education [24]. A highly

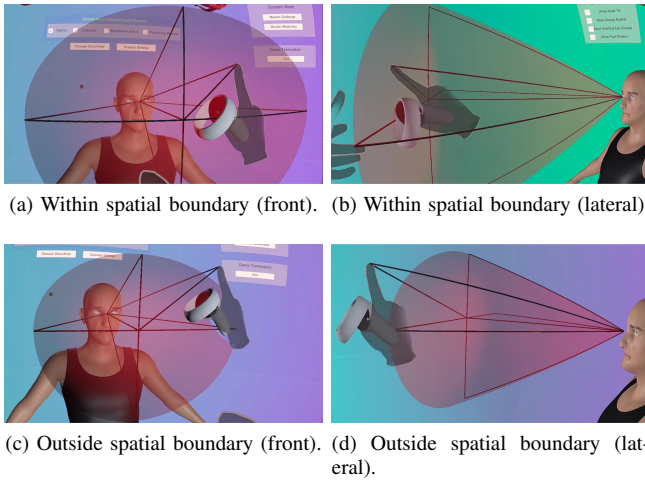


Fig. 3: VR patient's eye tracking model (left eye).

reproducible human body is shaped with sophisticated modelling, high-motion DOF, and deformable morphs for the VR patient design. Apart from accurate and realistic eye movement simulation, these features also contribute to visualising other concomitant symptoms (*e.g.* ptosis, pupil dilation, head tilt). The VR patient character is also designed in a neutral style without animation and racial characteristics to ensure medical ethics and universal applicability in different educational environments.

The 3D UI elements are implemented in the scene with a wrap-around space layout [25]. The secondary controller emits a raycast that the student can utilise to manipulate remote UI elements with a projected cursor. Therefore, the student may focus on interacting with the VR patient rather than being sidetracked by extra movement to engage with the UI elements. The UI elements are segregated into two categories according to their functional attribute. As illustrated in Fig. 4, the orange-coloured area includes the UI elements used across different scenario modes. The student can freely change the scenario mode and system language through them. In addition, they also allow the student to enable or disable the extraocular muscle models and accompanying symptoms of specific disorders. The yellow-coloured area includes the UI elements dedicated to specific scenario modes. The UI elements in this category are the primary object that the student uses to alter the VR patient's symptoms or give diagnostic feedback.

D. Disorder Symptom Demonstration

The Disease Demo Scenario presents the visualised symptoms of specific neuro-ophthalmologic disorders. This scenario mode provides the student with a multi-perspective view to observe the symptoms of multiple kinds of common neuro-ophthalmologic disorders, giving an intuitive experience to memorise symptomatic manifestation and comprehend underlying principles. The VR patient may suffer from either unilateral or bilateral symptoms, depending on the disorder type [2] [21]. Therefore, the student can select desired unilateral

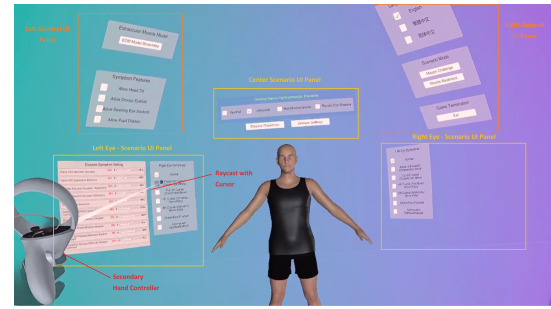


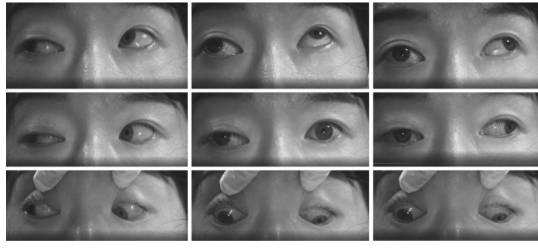
Fig. 4: User interface of MetaNODES.

symptoms by activating the corresponding toggles on the right or left scenario UI panel for each eye. Conversely, selecting the toggles on the centre UI scenario activates corresponding bilateral disorder symptoms and disables the unilateral symptom toggle panels.

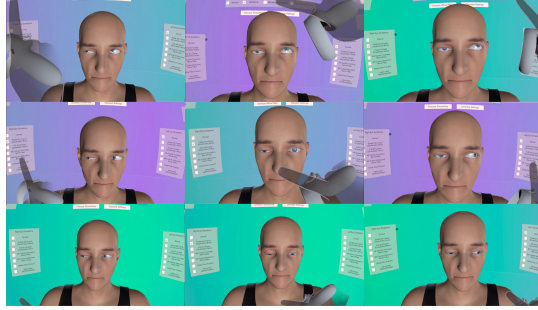
The MetaNODES system realises symptoms reproduction of common neuro-ophthalmologic disorders, including eye-involved cranial palsies, internuclear ophthalmoplegia, orbital floor fracture, myasthenia gravis, and thyroid eye disease [26] [27] [28]. To visualise the symptoms of these disorders, a spatial algorithm for control of eye movement limitation and deviation is designed based on the model proposed in Section II-B. The algorithm dynamically retrieves and updates the spatial boundary and eye movement deviation according to the student's choice. Under the expert's evaluation and feedback, this algorithm performs a realistic simulation of different symptoms. Fig. 5 shows a comparative example between a real patient and our VR patient, both with partial third nerve palsy disorder. Additionally, the system is capable of simulating disorders with arbitrary symptom patterns (*e.g.* myasthenia gravis, thyroid eye disease) [30] [31]. For instance, myasthenia gravis may randomly weaken patients' ocular motility in different gaze directions. Therefore, a randomisation feature is introduced to guarantee their symptoms fluctuate without repetition. There exists considerable flexibility for instructors to customise the symptoms. The severity of the different disorders and the presence or absence of accompanying symptoms can be readily modified by utilising the appropriate UI elements.

E. Extraocular Muscle Weakness Explanation

Instead of memorising symptoms, students are also supposed to grasp the underlying physiological and anatomical principles. The movements of human eyes are facilitated through the coordinated regulation of six extraocular muscles. The weakened strength of the extraocular muscles is correlated with the dysfunction of the nerves responsible for their control [32] [33]. The explanation of synergy and antagonistic effect between extraocular muscles in ocular motility has been a difficult task. The Muscle Weakness Scenario allows the student to observe how the weakened extraocular muscles influence ocular motility in a quantifiable way. Different from Section II-D, another continuous spatial algorithm is deployed



(a) Partial third cranial nerve palsy symptoms of a real patient (adapted from [29]).



(b) Partial third cranial nerve palsy symptoms simulated by our algorithm.

Fig. 5: Comparison between symptom on real patient and our VR patient.

to simulate the bio-mechanics of six extraocular muscles. Once the student tunes each muscle's weakness slider, the algorithm updates the parameter to calculate the new spatial boundary and gaze angle deviation. The student can intuitively observe the symptoms of different levels of extraocular muscle weakness brought on by neurological disorders.

F. Gamified Learning with Mission Challenge

Due to the complexity of medical knowledge, passive learning mode can significantly reduce students' learning interest and motivation. Gamified learning, as an effective educational strategy, can leverage the game's incentive mechanism to engage students in active learning [15] [34]. The powerful stereoscopic interactivity of VR HMD devices opens up new opportunities for gamified neuro-ophthalmology training. Thus, the Game Mission Scenario is designed as a helpful platform, serving both purposes of exercise and assessment. It presents an interactive quiz game of simulated diagnostic tasks in a 3D environment.

In the quiz, the student is required to accurately identify the disorder type in each mission within a designated time constraint. They need first to use the primary controller to guide the VR patient's gaze and carefully observe the symptoms. Subsequently, their answer should be selected and submitted through the toggles corresponding to different bilateral or unilateral symptom disorders. For unilateral cases, they have to choose the correct disorders for both eyes. Following each attempt, the accurate solution is displayed to inform the student whether they have made a correct diagnosis in the previous mission. A statistical report is produced at the

end of a mission game to help the student to evaluate their performance. In the exercise, the student can freely adjust the mission numbers and time limit of randomised disorder sequences according to their level of mastery. The instructor can further deploy customised disorder sequences with the draggable cell UI elements for test purposes.

The Game Mission Scenario leverages the same spatial algorithm elaborated in Section II-D. The distinction is that the Game Mission Scenario incorporates a queue structure for storing predetermined disorder sequences. A finite state machine (FSM) embedded in the game mission controller takes charge of the game process. It feeds randomly generated or customised disorder sequences into the queue during the initialisation phase of the game. In each mission, the FSM pops the disorder element at the front of the queue and hands it over to the spatial algorithm for execution. The FSM forwards the game to termination when the queue is detected empty.

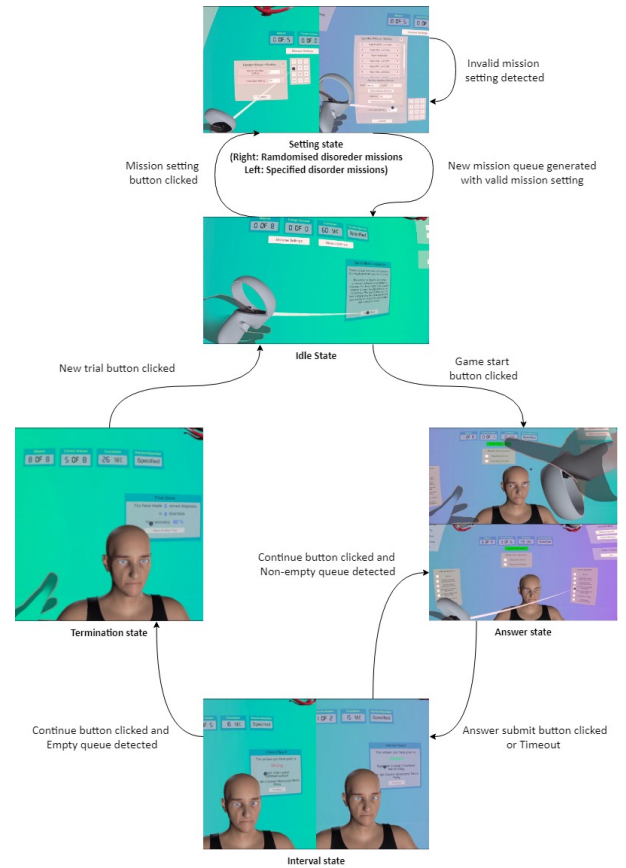


Fig. 6: State transfer diagram of gamified learning.

III. EVALUATION AND RESULT

To evaluate the teaching performance of the MetaNODES system, a questionnaire survey was conducted on 23 students who had utilised the system for experimental learning. The assessment criteria of the questionnaire were quantified on a score range from 1 to 10. As illustrated in Table. I, the tested students were highly satisfied with using the MetaNODES

system in neuro-ophthalmology education, giving an average comprehensive satisfaction score of 8.52 out of 10. The result pointed out that the system performed well in the simulation of the clinical diagnosis process. Most students considered that the system facilitated their study with better engagement and higher motivation. The majority of the evaluated students found that VR-based interactive learning was more acceptable to them than the traditional medical training methods.

The comfort of wearing a VR device and the ease of use of 3D UI elements presented a relatively unsatisfactory performance. In comment feedback, it was noticed that some students experience motion sickness in the VR learning environment. Additionally, students unfamiliar with VR operation found it challenging to immediately use the controller for smooth 3D UI interactions.

TABLE I: Questionnaire survey result of MetaNODES

Assessment Criteria	Mean Score
Fidelity of the VR patient's appearance (eyes and facial expression)	8.62
Realism of gesture interaction with the VR patient	8.74
Comfort of wearing VR device	6.32
Ease of operating VR hand controllers	8.22
Ease of use of 3D UI elements	7.68
Realism and clarity of disorder symptoms simulation	8.66
Facilitation in knowledge memorisation	8.32
Facilitation in understanding principles	8.57
Facilitation in discuss with other students and instructor	8.17
Engagement with study in VR environment	8.82
Interest and motivation of learning in VR environment	8.68
Superiority over traditional education method	8.77
Comprehensive satisfaction score	8.52

IV. CONCLUDING REMARKS

The MetaNODES system presents a groundbreaking approach to employing cutting-edge HCI technology in facilitating complex medical education. To our knowledge, this is the first attempt to deploy VR HMD devices for comprehensive medical training in neuro-ophthalmological diagnosis. The immersive and interactive learning environment created by the Oculus Quest 2 and the Unity game engine offers a realistic clinical scenario for students to learn beyond space limitations. The result shows that the MetaNODES system enhances teaching efficiency.

Future work will focus on integrating augmented reality (AR) into the MetaNODES system on more potent VR HMD devices. Reduced exposure to VR motion sickness and a feeling of detachment from reality is anticipated for students.

Furthermore, with the future exploration of multi-user deployment in the decentralised online learning environment, the MetaNODES system is supposed to be a paradigm for medical education in the metaverse.

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REFERENCES

- [1] D. D. C. S. Dutt, S. E. Carr, T. M. Scott, C. Petsoglou, J. Grigg, and H. Razavi, 'Educators' consideration of learner motivation in ophthalmology education in medical school: Influences on teaching practice and course design', *Medical teacher*, vol. 46, no. 3, pp. 387–12, 2024.
- [2] J. Somlai and T. Kovács, *Neuro-ophthalmology*. Switzerland: Springer, 2016.
- [3] J. J. S. Barton and A. Leff, *Neurology of vision and visual disorders*. in Issn. Amsterdam, Netherlands: Elsevier, 2021.
- [4] ['UC San Diego's Practical Guide to Clinical Medicine'. Accessed: Jun. 17, 2024. [Online]. Available: <https://meded.ucsd.edu/clinicalmed/eyes.html>
- [5] J. Jang, Y. Ko, W. S. Shin, and I. Han, 'Augmented Reality and Virtual Reality for Learning: An Examination Using an Extended Technology Acceptance Model', *IEEE Access*, vol. 9, pp. 6798–6809, 2021.
- [6] J. Pirker and A. Dengel, 'The Potential of 360° Virtual Reality Videos and Real VR for Education—A Literature Review', *IEEE Computer Graphics and Applications*, vol. 41, no. 4, pp. 76–89, Jul. 2021.
- [7] S. Barteit, L. Lanfermann, T. Bärnighausen, F. Neuhann, and C. Beiersmann, 'Augmented, Mixed, and Virtual Reality-Based Head-Mounted Devices for Medical Education: Systematic Review', *JMIR Serious Games*, vol. 9, no. 3, p. e29080, Jul. 2021.
- [8] J. W. V. de Faria, M. J. Teixeira, L. de M. S. Júnior, J. P. Otoch, and E. G. Figueiredo, 'Virtual and stereoscopic anatomy: when virtual reality meets medical education', Nov. 2016.
- [9] A. J. Lungu, W. Swinkels, L. Claesen, P. Tu, J. Egger, and X. Chen, 'A review on the applications of virtual reality, augmented reality and mixed reality in surgical simulation: an extension to different kinds of surgery', *Expert Review of Medical Devices*, vol. 18, no. 1, pp. 47–62, Jan. 2021.
- [10] M. A. Zielke et al., 'Developing Virtual Patients with VR/AR for a natural user interface in medical teaching', in 2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH), Apr. 2017, pp. 1–8.
- [11] M. Iskander, T. Ogunsola, R. Ramachandran, R. McGowan, and L. A. Al-Aswad, 'Virtual Reality and Augmented Reality in Ophthalmology: A Contemporary Prospective', *Asia-Pacific Journal of Ophthalmology*, vol. 10, no. 3, pp. 244–252, May 2021.
- [12] E. G. Muñoz, R. Fabregat, J. Bacca-Acosta, N. Duque-Méndez, and C. Avila-Garzon, 'Augmented Reality, Virtual Reality, and Game Technologies in Ophthalmology Training', *Information*, vol. 13, no. 5, Art. no. 5, May 2022.
- [13] A. A. Kononowicz et al., 'Virtual Patient Simulations in Health Professions Education: Systematic Review and Meta-Analysis by the Digital Health Education Collaboration', *Journal of Medical Internet Research*, vol. 21, no. 7, p. e14676, Jul. 2019.
- [14] S. Kloiber et al., 'Immersive analysis of user motion in VR applications', *Vis Comput*, vol. 36, no. 10, pp. 1937–1949, Oct. 2020.
- [15] A. N. Saleem, N. M. Noori, and F. Ozdamli, 'Gamification Applications in E-learning: A Literature Review', *Tech Know Learn*, vol. 27, no. 1, pp. 139–159, Mar. 2022.
- [16] M. Sailer and L. Homner, 'The Gamification of Learning: a Meta-analysis', *Educ Psychol Rev*, vol. 32, no. 1, pp. 77–112, Mar. 2020.
- [17] J. Schild et al., 'Applying Multi-User Virtual Reality to Collaborative Medical Training', in 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Mar. 2018, pp. 775–776.
- [18] C. Hillmann, 'Comparing the Gear VR, Oculus Go, and Oculus Quest', in *Unreal for Mobile and Standalone VR: Create Professional VR Apps Without Coding*, C. Hillmann, Ed., Berkeley, CA: Apress, 2019, pp. 141–167.

- [19] V. Holzwarth, J. Gisler, C. Hirt, and A. Kunz, 'Comparing the Accuracy and Precision of SteamVR Tracking 2.0 and Oculus Quest 2 in a Room Scale Setup', in Proceedings of the 2021 5th International Conference on Virtual and Augmented Reality Simulations, in ICVARS '21. New York, NY, USA: Association for Computing Machinery, 2021, pp. 42–46.
- [20] J. Jerald, P. Giokaris, D. Woodall, A. Hartholt, A. Chandak, and S. Kuntz, 'Developing virtual reality applications with Unity', in 2014 IEEE Virtual Reality (VR), Mar. 2014, pp. 1–3.
- [21] A. M. Ansons, *Diagnosis and management of ocular motility disorders*, Fourth edition. Chichester, West Sussex, UK: Wiley Blackwell, 2014.
- [22] H. W. Lim et al., 'Clinical Measurement of the Angle of Ocular Movements in the Nine Cardinal Positions of Gaze', *Ophthalmology* (Rochester, Minn.), vol. 121, no. 4, pp. 870–876, 2014.
- [23] W. J. Lee, J. H. Kim, Y. U. Shin, S. Hwang, and H. W. Lim, 'Differences in eye movement range based on age and gaze direction', *Eye* (London), vol. 33, no. 7, pp. 1145–1151, 2019.
- [24] T. Baniyadi, S. M. Ayyoubzadeh, and N. Mohammadzadeh, 'Challenges and Practical Considerations in Applying Virtual Reality in Medical Education and Treatment', *Oman Med J*, vol. 35, no. 3, p. e125, May 2020.
- [25] J. J. LaViola, *3D user interfaces: theory and practice*, Second edition. in Addison-Wesley usability and HCI series. Boston: Addison-Wesley, 2017.
- [26] D. K. Binder, *Cranial nerves: anatomy, pathology, imaging*. Stuttgart ; Thieme, 2010.
- [27] S. P. Liversedge, I. D. Gilchrist, and S. Everling, *The Oxford handbook of eye movements*. in [Oxford library of psychology]. Oxford ; Oxford University Press, 2011.
- [28] A. G. Shaikh and F. Ghasia, *Advances in translational neuroscience of eye movement disorders*. in Contemporary clinical neuroscience. Cham: Springer, 2019.
- [29] G. Tian, X. Sun, and C. Feng, 'Multiple Cranial Nerve Palsy', in *Neuro-Ophthalmology: Case Based Practice*, G. Tian and X. Sun, Eds., Singapore: Springer Nature, 2022, pp. 479–490.
- [30] A. Engel, *Myasthenia gravis and myasthenic disorders*, 2nd ed. in Contemporary neurology series, no. 81. New York: Oxford University Press, 2012.
- [31] R. S. Douglas, A. N. McCoy, and S. Gupta, *Thyroid eye disease*. New York, NY: Springer, 2015.
- [32] A. Lens, *Ocular anatomy and physiology*, 2nd ed. Thorofare, NJ: Slack, 2008.
- [33] M. W. Ansari, *Atlas of Ocular Anatomy*, 1st ed. 2016. Cham: Springer International Publishing, 2016.
- [34] S. Subhash and E. A. Cudney, 'Gamified learning in higher education: A systematic review of the literature', *Computers in Human Behavior*, vol. 87, pp. 192–206, Oct. 2018.