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Integrating Sustainable Concepts into Blended Learning and Interactive Game System Design †

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Abstract: Food is essential for sustaining human life. While people love delicious food, they often neglect the care for it. One of the most commonly wasted foods is bread. There has not been much research on bread waste. Carbon emissions from bread are not less than those from meat products. Therefore, it is necessary to integrate sustainable concepts with mixed learning approaches into a mixed reality (MR) interactive system, focusing on bakeries. We conducted field research and observations of leftover bread from eight local bakeries, categorizing and photographing them. We combined knowledge and teaching about carbon emissions with interactive games to help users understand the relationship between bread and carbon emissions. Users can learn about relevant knowledge and content by playing the MR game. The interactive game provides a reference for sustainability research in the future.

Keywords: sustainable concepts; blended learning; mixed reality; game design; leftover bread

1. Introduction

According to data obtained from the Macao Special Administrative Region (Environmental Protection Bureau) in 2023 [1], about 40% of food waste in Macau originated from restaurants, hotels, supermarkets, and similar establishments. Bread waste represents a significant portion of food waste. A local survey conducted on eight bakeries in Macau (including Lisboa Bakery, Fong Kei Bakery, Maxim's Cake, Koi Kei Bakery, Goat Bakers, Anak Philippine Bread, Saint Honore Cake Shop, and Kee Wah Bakery) showed while these bakeries sell a certain amount of bread, a considerable portion remains unsold. Most bakeries attempt to reduce bread waste by promoting buy-two-get-one-free deals, discounts, or by distributing the leftovers to employees while considering freshness and food safety.

Despite these efforts, much of the bread is still discarded every day. Due to this issue, companies and institutions have introduced various initiatives. For instance, Beans Bakery in the Hong Kong and Macau region has adopted a flexible pricing plan for leftover bread, where bread waste is placed outside the store after business hours, allowing customers to purchase it at a self-determined price [2]. Additionally, the non-profit charity Wefood Macau recycles still-edible surplus food in the local food and retail sectors and distributes it for free to individuals or groups in need through donations or events [3].

Beyond purchasing behavior, consumers must learn about and understand sustainable concepts. Albrecht et al. developed an iPhone/iPad application to teach families with young children how to safely handle leftover food. The application provides different food-related information and highlights the potential risks of falling ill from leftover food [4].

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Perceived behavioral control and personal norms established through an awareness of consequences and responsibility attribution help to reduce food waste [5]. This illustrates the impact and changes by using technology. Chai et al. applied augmented reality (AR) and mixed reality (MR) to food-related fields to provide information on dietary assessment, food nutrition and traceability, food retail chain applications, and food education and learning. They discussed the challenges and issues related to the use of AR/MR in food-related studies while highlighting research needs and directions for the development of AR/MR applications in the food industry [6]. Immersive experiences improve nutrition research by enhancing the aspects of control, adaptability, realism, and mobility and by offering information on food choice, education, and cognition [7–9].

The issue of food waste has gained global attention and has been integrated with technological applications. However, bread has been overlooked. Therefore, by integrating sustainable concepts with an MR-based interactive game, environmental knowledge and relationships between carbon footprints and bread can be delivered. We developed one such integrated system that provides an immersive experience using Unity 3D as the platform and Meta Quest3 as the hardware. Blended learning is also combined for online and offline learning and to assess feasibility. The developed system provides sustainable concepts based on the results of investigating bread waste in local bakeries. The concept of carbon footprints is integrated with an MR game. By exploring how blended learning is combined with an MR interactive game, the game's playing methods and a system design model were created to enable online and offline learning and to assess their feasibility.

2. Literature Review

2.1. Leftover Bread and Carbon Footprints

Macau's tourism industry has now recovered in this post-pandemic era. While consumer spending is increasing, the food waste index has also risen. The waste of easily accessible bread from supermarkets is often overlooked. The carbon footprint (CF) estimation is an objective and stable method for assessing the sustainability of food consumption. Such information serves as a basis for consumer choices, enabling them to make informed decisions and to achieve sustainability with effective food choices [10]. Related studies have examined various types of bread products, including white bread, whole wheat bread, and rye bread, as well as mixed items of such types. Greenhouse gas emissions have been estimated throughout the entire supply chain for 1 kg of white or rye bread before they reach the retail market. White bread has a slightly lower carbon footprint than rye bread [11,12]. The Environmental Information Center (EIC) calculated carbon dioxide emissions (CO_2e) in relation to the global warming potential (GWP) and used this indicator as the standard unit for measuring the carbon footprints of food and raw materials. For example, 1 kg of eggs has a carbon footprint of 3.2 kg of CO_2e, suggesting that larger volumes of bread with more ingredients result in a higher carbon footprint and contribute more significantly to the greenhouse effect.

2.2. MR Interactive Experience

Sutherland developed a head-mounted display that could overlay reality with the virtual world, allowing users to walk around in physical space and engage in other interactive experiences [13]. MR combines the real world with the virtual world by integrating physical and digital objects. Today, technological advancements enable MR to have a broad range of applications and development potential [14]. MR technology has been used to support assisted learning, and users' learning outcomes have significantly improved through learning experiences with MR. By understanding learning outcomes, esthetic enjoyment and interest can be increased to varying degrees [15,16]. Claudio and Chris explored the

education outside the classroom (EOTC) model by employing action-learning designs and integrating self-directed and free-choice learning for marine ecology. Through self-directed learning, users learned the content and obtained a multi-sensory experience involving tactile, visual, and auditory effects. The model enabled users to learn, understand, and engage with marine environmental protection topics. MR enhanced the comprehension of complex marine conservation and increased ecological literacy, attitudes, and behaviors. The research results showed a certain degree of correlation with knowledge and reasoning about real-world environmental protection [17].

2.3. Sustainable Concepts and the Blended Learning Model

Oliver and Trigwell defined blended learning as the combination of two or more learning methods [18]. Driscoll noted that blended learning takes various forms, such as integrating online technologies, instructional techniques, and actual work tasks [19]. The internet and computers play a crucial role in blended learning, supplementing traditional teaching with diverse materials, innovative learning activities, the implementation of complex tests, or self-assessments, where students score their outcomes through computer systems, actively review and evaluate their answers, and receive immediate feedback from the system. In K–12 classrooms, blended learning is used in the following models: (1) The rotation model, where students learn at their own pace through a combination of online learning, whole-class instruction, group projects, and individual tutoring. (2) The flex model, where students have complete freedom to choose a flexible learning schedule meeting their individual needs while also selecting their own learning pace. Teachers only provide course content and guidance when necessary, giving students a high degree of autonomy and control over their learning process. (3) The self-blended model, where schools offer a technology platform to deliver high-quality online courses through a learning management system. (4) The enriched virtual lab, where students conduct experiments and practice data analysis in an online virtual lab and allocate their time between campus and online learning by distance learning [20]. In related research, to feature interdisciplinary characteristics, a blended teaching model is used to foster students' awareness of environmental protection and sustainability with teaching resources [21]. Smart Education (2017 edition) highlights the ecological development concept, noting a shift from a "smart environment" to an "ecological environment" [22]. In ecological interactive classrooms, the reference for education and teaching models is reconstructed from perspectives of technology and culture to create a harmonious and symbiotic sustainable development model and the healthy development of ecological teaching by injecting vitality through interactive instruction [23]. Blended learning boasts learning advantages by incorporating different concepts of environmental protection and sustainability. It allows students to engage in learning science and technology, where learning outcomes and development are improved.

3. Research Method

We reviewed the literature on leftover bread and carbon footprints, MR interactive experiences, sustainable concepts, and blended learning models. Theories, developments, technologies, and designs were analyzed. We performed field research on eight local bakeries in Macau to observe the daily quantities and types of bread waste. The collected data were used for the system design. We also explored the concept of the carbon footprint, its calculation, and the relationship between the carbon footprint and bread. The results were integrated into an online teaching model (including images, text, and dynamic effects). The model was used to create an MR game for interactive learning for users to acquire knowledge through repeated experiences.

4. MR System

4.1. System Process

The game is operated in a question-and-answer format. The game consists of ten levels with increasing difficulty. The questions are either in multiple-choice or single-choice formats. For example, to the question "What is a carbon-reducing bread?", a single-choice answer is "Bread that reduces carbon emissions during production". For the question "How does purchasing 'carbon-reducing bread' benefit our lives?", answers are diverse, such as in the following: (1) Improves the environment and promotes human health; (2) Reduces resource waste and environmental burden; (3) Promotes local economic development; and (4) Raises environmental awareness. Users can conclude their online learning about the relationship between the carbon footprint and bread before engaging in the MR game. Figure 1 shows the MR system framework, which includes Unity 3D as the development tool and the interactive programming written in C#. The game incorporates leftover bread as game materials. The game is edited for visual effects and layout using Photoshop and Illustrator. It is deployed to the Quest 3 device for game testing and the game experience.

Figure 1. Website—main page and game levels. (Bread eliminate, Start button, Exit button, Settings and 10 level selection).

The MR system comprises a main menu interface, a settings page, the game mode, game instructions, the game content, and an end/reward page.

The main menu interface introduces the game content, named "Bread Elimination", featuring the basic user interface with options to start and exit and to configure the settings. On the settings page, the weapon switch (rolling pin and mixer) and music, font selection, speed adjustments, and other functions are introduced. Easy or difficult modes can be selected, with the latter featuring faster speed and quicker obstacle settings compared with the former, presenting an overall higher difficulty level. The guiding interface assists players in their game experience, guiding operation methods, level settings, and game explanations. The main element of the game is bread (black bread and white bread). Players score points by using a mixer or rolling pin to strike the bread on an educational interface, gaining five carbon footprint points for hitting black bread and losing five carbon footprint points for hitting white bread. Correct answers allow players to continue, while incorrect ones end the game. The maximum total score is 300 points, with over 40 points required to advance to the next level. The score is calculated after the game is over, providing basic criteria to restart the game or to proceed to the next level. The score is then ranked, rewarding the high-performing players.

4.2. System Interface

The system UI improves the user experience through its visual appeal and functional usability (Figure 1). Popular mobile games such as "Honor of Kings", "Game for Peace", and various parkour games prioritize simple functionality, ensuring usability while maintaining the esthetic quality. We focused on the usability of the UI design to streamline unnecessary decorations while considering user demands. The design elements are presented in Figures 2 and 3. Many bread icons (e.g., croissants, sourdough, cinnamon roll, German reduced-water bread, brioche, etc.) are offered with a warm yellow background color to enhance users' memory of and association with bread.

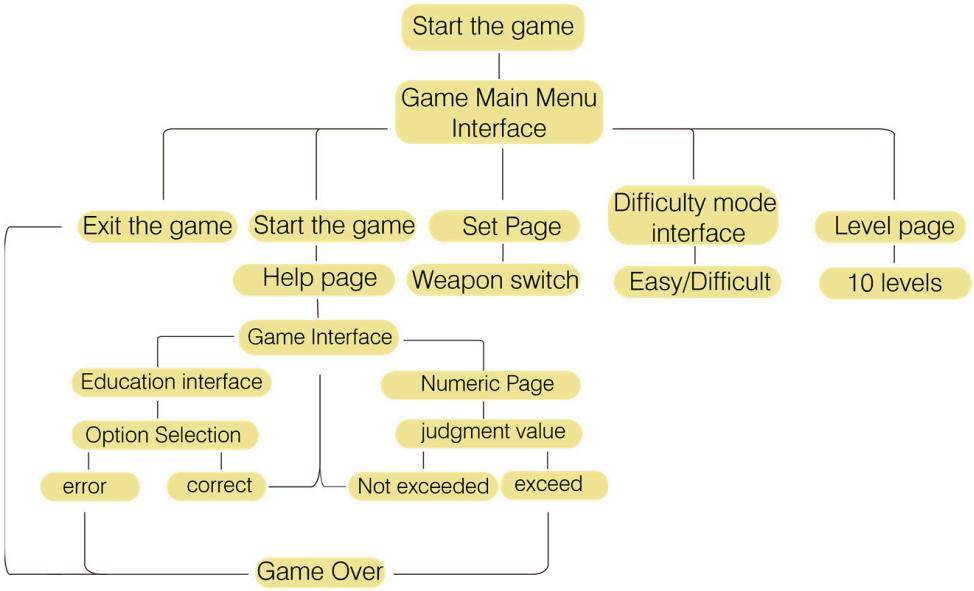

Figure 2. Conceptual framework of the game system (researchers' own drawings).

Figure 3. Last page of the game. (This content is the question-and-answer interface in the game system and the score screen at the end of the game.)

UI design tools such as Procreate 5.3.5 and Photoshop for artistic page effects are used in the game. After coding, Unity 3Dis used for the game (Figure 4). The game is ported in the APK format. SideQuest software is used as the medium between the computer to present the game effect on Quest 3.

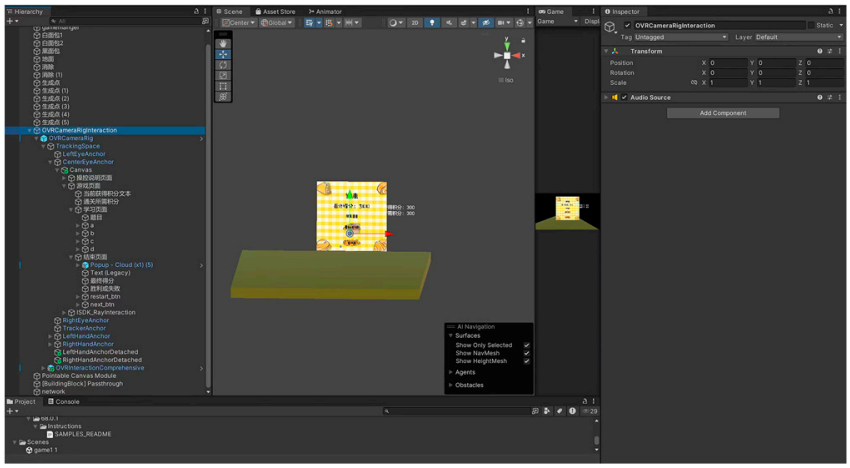

Figure 4. Unity 3D system content design.

5. Online and Offline Blended Learning

The interactive experience design for blended learning combines blended learning content. The learning content enables "Web online" and "face-to-face" offline game experiences in blended learning to educate users about leftover bread and other related knowledge.

5.1. Web Online Learning

In this research study, online learning on the internet allows instructors to impart knowledge on a computer platform (Figure 5). The content includes introducing leftover bread in Macau, reasons for its surplus, and the carbon footprint of bread. The total greenhouse gas emissions for 1 kg of rye bread are approximately 790 g [24]. The total carbon emissions throughout the life cycle of bread are significant. According to the Ministry of Ecology and Environment, one tree absorbs about 18.3 kg of CO_2 a year, which is equivalent to the emissions from 23 kg of black bread. Excessive carbon emissions lead to extreme weather, accelerate glacier melting, and pose health risks. To reduce the carbon footprint, consumers are recommended to utilize reusable bags and to refuse food waste. The game educates users on how to manage leftover bread, understand the hazards of food waste, and acquire knowledge about sustainable concepts and the carbon footprint of bread.

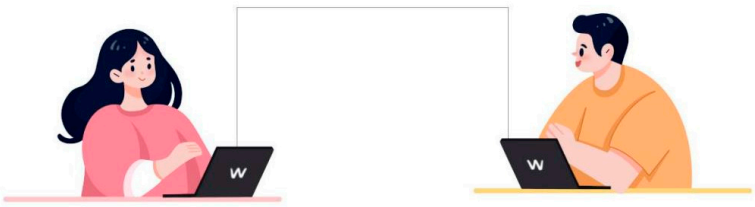

Figure 5. Web-based learning (professor on the right and learner on the left).

For the carbon footprint calculation, life cycle assessment (LCA) and emissions from energy fossil fuels (IPCC) are used. In online learning, the images taken at the bakeries are organized and combined with texts. The stages of the bread life cycle include the raw materials, transportation, baking, packaging, distribution, and final disposal (Figure 6). Users can acquire the relevant knowledge and understand sustainable concepts.

Figure 6. Bread life cycle diagram.

5.2. Face-to-Face Offline Learning

Face-to-face learning focuses on interactive game experiences and facilitates the learning of sustainable concepts. The game test venue is a bakery in Macau (Figure 7).

Figure 7. Game testing area—bakery.

In the game scene design, program levels are set by creating scenes and using the game manager (Script) to establish the opening levels. The game's interaction mode employs ray interaction, allowing players to enter levels by clicking with their controllers. Players can earn carbon footprint points by striking the bread (Figures 8 and 9). Educational prompts appear during gameplay to ask the players questions. Correct answers and certain points allow users to progress (Figure 10).

Figure 8. Black bread & Game score and carbon footprint points.

Figure 9. White bread & Game score and carbon footprint points.

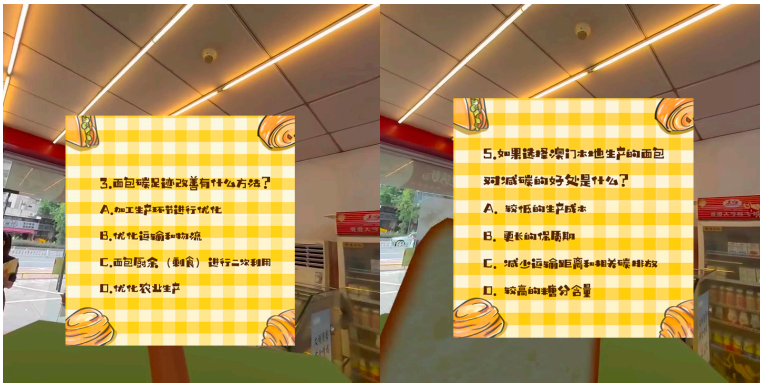

Figure 10. Single-choice and multiple-choice questions. (Asked about ways to improve the carbon footprint of bread? And What are the benefits of choosing bread produced locally in Macau in reducing carbon emissions?).

Through online dissemination and offline game tests, users can acquire leftover-food-related knowledge online and engage in experiential learning through offline gameplay too (Figure 11). This approach expands the learning experience and effectively disseminates leftover-bread-related content, allowing users to learn about and understand sustainable concepts.

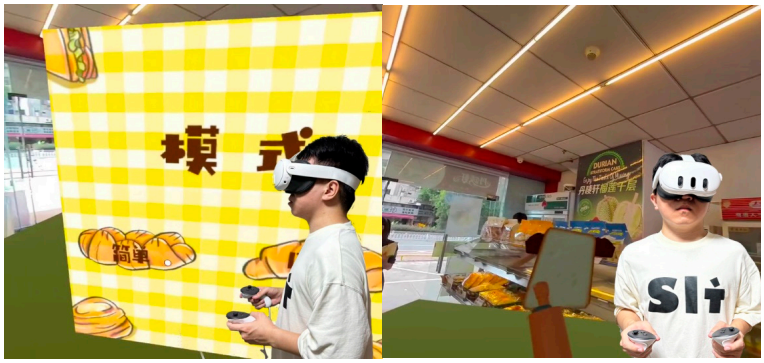

Figure 11. Game experience process. (Game Mode and Selection Screen).

6. Conclusions and Recommendations

Following data collection from bakeries in the Macau region, the survey content has been created, focusing on leftover bread. The target audience is students with prior experience using digital devices. To assist them in acquiring knowledge related to leftover bread and sustainable concepts, the UI design and MR game interaction has been developed. The perspectives mentioned at the IEEE VR conference—Cognition, Game User Experience, Presence, and Vector—can be applied to evaluate VR system experiences. The game experience questionnaire (GEQ) and the questionnaire of user interface satisfaction (QUIS) also need to be integrated for game assessments [25]. The developed MR system in this study extends the sustainability theory and provides information for the future development of leftover-food-related games.

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References

1. Macau Environmental Protection Bureau. Featured Projects. Available online: https://www.dspa.gov.mo/index.aspx (accessed on 2 October 2024).
2. Liou, J.T. BEANS Coffee. Dessert. Light Meal. UpToDate. 2023. Available online: https://www.facebook.com/beanscafe.hk/ (accessed on 2 October 2024).
3. Macao Central, Macao Cherish Food Non-Profit Organization. UpToDate. 2017. Available online: https://www.macaucentral.com/community/21256-wefood-macau (accessed on 2 October 2024).
4. Albrecht, J.A.; Larvick, C.; Weishaar, C. Leftovers and Other Food Safety Information for iPhone/iPad Application ("Smartphone" Technology). *J. Nutr. Educ. Behav.* **2012**, *44*, 469–471. [CrossRef]
5. Setiawan, B.; Purwanto, P.; Ikasari, W.S.D.; Suryadi, S. An inclusive extension of the Theory of Planned Behavior for explaining household food leftover reduction intention among Gen Z. *J. Soc. Mark.* **2024**, *14*, 328–346. [CrossRef]
6. Chai, J.J.K.; O'Sullivan, C.; Gowen, A.A.; Rooney, B.; Xu, J.-L. Augmented/mixed reality technologies for food: A review. *Trends Food Sci. Technol.* **2022**, *124*, 182–194. [CrossRef]

7. McGuirt, J.T.; Cooke, N.K.; Burgermaster, M.; Enahora, B.; Huebner, G.; Meng, Y.; Tripicchio, G.; Dyson, O.; Stage, V.C.; Wong, S.S. Extended reality technologies in nutrition education and behavior: Comprehensive scoping review and future directions. *Nutrients* **2020**, *12*, 2899. [CrossRef] [PubMed]
8. Liu, R.; Hooker, N.H.; Parasidis, E.; Simons, C.T. A natural experiment: Using immersive technologies to study the impact of "all-natural" labeling on perceived food quality, nutritional content, and liking. *J. Food Sci.* **2017**, *82*, 825–833. [CrossRef]
9. Long, J.W.; Pritschet, S.J.; Keller, K.L.; Cheah, C.S.L.; Boot, L.; Klippel, A.; Brick, T.R.; Edwards, C.G.; Rolls, B.J.; Masterson, T.D. Portion size affects food selection in an immersive virtual reality buffet and is related to measured intake in laboratory meals varying in portion size. *Appetite* **2023**, *191*, 107052. [CrossRef] [PubMed]
10. Bschaden, A.; Bopp, C.; Rüdiger, A.; Strobel, L.; Stroebele-Benschop, N. Carbon footprints on the menu: Exploring consumer choices and perceptions across real-world gastronomic settings. *J. Clean. Prod.* **2024**, *463*, 142773. [CrossRef]
11. Čuček, L.; Klemeš, J.J.; Kravanja, Z. A review of footprint analysis tools for monitoring impacts on sustainability. *J. Clean. Prod.* **2012**, *34*, 9–20. [CrossRef]
12. Jensen, J.K.; Arlbjørn, J.S. Product carbon footprint of rye bread. *J. Clean. Prod.* **2014**, *82*, 45–57. [CrossRef]
13. Mann, S. Wearable computing: A first step toward personal imaging. *Computer* **1997**, *30*, 25–32. [CrossRef]
14. Allcoat, D.; Hatchard, T.; Azmat, F.; Stansfield, K.; Watson, D.; Mühlenen, A.V. Education in the digital age: Learning experience in virtual and mixed realities. *J. Educ. Comput. Res.* **2021**, *59*, 795–816. [CrossRef]
15. Tang, Y.M.; Au, K.M.; Lau, H.C.W.; Ho, G.T.S. Evaluating the effectiveness of learning design with mixed reality (MR) in higher education. *Virtual Real.* **2020**, *24*, 797–807. [CrossRef]
16. Chin, K.Y.; Chang, H.L.; Wang, C.S. Applying a wearable MR-based mobile learning system on museum learning activities for university students. *Interact. Learn. Environ.* **2023**, *32*, 5744–5765. [CrossRef]
17. Claudio, A. Using mixed reality (XR) immersive learning to enhance environmental education. *J. Environ. Educ.* **2023**, *54*, 58–71.
18. Oliver, M.; Trigwell, K. Can 'blended learning' be redeemed? *e-Learn. Digit. Media* **2005**, *2*, 17–26.
19. Driscoll, M. Blended learning: Let's get beyond the hype. *e-Learning* **2002**, *3*, 1–2.
20. Spanjers, I.A.; Könings, K.D.; Leppink, J.; Verstegen, D.M.; de Jong, N.; Czabanowska, K.; van Merriënboer, J.J. The promised land of blended learning: Quizzes as a moderator. *Educ. Res. Rev.* **2015**, *15*, 59–74. [CrossRef]
21. Feng, D.Q.; Liu, G.L.; Mao, A.R.; Sun, M.Z.; Zhang, B.B. Internet-based practice of blended teaching in environmental and sustainable development courses. *Electron. Technol.* **2020**, *7*, 68–69.
22. Vladimir, L.U.; Robert, J.H.; Lakhmi, C.J. Smart Education and e-Learning 2017. In Proceedings of the 4th International KES Conference on Smart Education and Smart E-Learning (KES-SEEL-17), Vilamoura, Portugal, 21–23 June 2017.
23. Qi, Y.T. Research on design methods and practices of mixed reality interactive software. *Screen Print.* **2024**, *10*, 108–110.
24. Nielsen, P.H.; Dalgaard, R.; Korsbak, A.; Pettersson, D. Environmental assessment of digestibility improvement factors applied in animal production: Use of Ronozyme® WX CT xylanase in Danish pig production. *Int. J. Life Cycle Assess.* **2008**, *13*, 49–56.
25. Kruijff, E.; Riecke, B.E. Navigation interfaces for virtual reality and gaming: Theory and practice. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems, Proceedings of the CHI Conference on Human Factors in Computing Systems, Montreal QC Canada, 21–26 April 2018*; Association for Computing Machinery: New York, NY, USA, 2018; pp. 1–4.