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Review Article

Leveling up orthodontic education: Game-based learning as the new frontier in orthodontic curriculum

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Abstract
Game-based learning (GBL) is becoming a focal point in contemporary orthodontic dental education. This study examines GBL's ability to provide immersive experiences simulating real-world orthodontic practice. Leveraging technologies like virtual reality (VR), augmented reality (AR), 3D modeling, and advanced e-learning platforms, GBL enhances active learning, critical thinking, and decision-making skills. While promising, GBL adoption faces challenges like high costs, technical demands, and curriculum integration hurdles. However, ongoing innovations, personalized learning paradigms, and artificial intelligence (AI) are mitigating these. This research highlights GBL's measurable impact on student engagement, information retention, and translating theory into orthodontic practice. Through GBL's lens, orthodontic education undergoes a paradigm shift where students construct comprehensive treatment plans for simulated patients, fulfilling modern orthodontic pedagogy's evolving requirements.

Introduction

Orthodontic therapy is a specialized therapy that improves dental and facial aesthetics[1] by correcting dental or skeletal abnormalities. Brackets, arch wires, and other components move teeth over time.[2] Orthodontic professionals must meticulously plan, monitor, and respond to the procedures as necessary. Treatment time might range from months to years, depending on the complexity of the case and the intended objective.[3,4] This adaptable treatment approach treats many malocclusions and other complex craniofacial abnormalities. Orthodontists employ treatment planning and customized modifications to promote functional occlusion and harmonious facial aesthetics.[1]

While traditional methods of learning, involving textbooks and seminars, provide a theoretical framework, practical training is crucial in equipping dental and or specialist orthodontic practitioners with the skills to perform successful orthodontic therapy.[5] The hands-on aspect of orthodontic procedures, on the other hand, might be difficult to recreate purely through standard instructional techniques. This has led to the investigation of novel strategies, including game-based learning (GBL), to improve the simulation of dental therapy and provide undergraduate learners with a more immersive and practical learning experience.[6] In today's constantly evolving educational approaches with learning preferences leaning more towards hands-on experiences gained during practical sessions, traditional teaching approaches are fast becoming obsolete.[7] Learners are becoming more aware and curious about the world around them as information becomes more widely available and technological advances become more sophisticated. It is our obligation as educators to adapt and embrace new technology-based techniques to meet their needs.[8] We can develop engaging and dynamic learning experiences that correspond with the digital age by using new tools and approaches such as GBL, among other tools.[9,10] These methods leverage learners' innate fascination with technology, encouraging active involvement, critical thinking, and problem-solving abilities. We can enable learners to explore, create, and link information in ways that resonate with their digital mentality by keeping up with the times and embracing technology, eventually equipping them for success in an increasingly digital world.[11] Game-based methods of learning have been developed to enhance simulation and provide undergraduate students with a more immersive experience. This learning method has the potential to transform undergraduate education by attempting to bridge the theoretical knowledge and practical application gap in orthodontic fixed therapy.[12] GBL has drawn a

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lot of attention as an innovative educational technique that blends the compelling characteristics of games with organized learning objectives.[12,13] This paper explores GBL processes and if GBL may be utilized to simulate in undergraduate education, highlighting its benefits, advantages, challenges, and limitations. GBL techniques are explored in terms of their impact on learner engagement, skill development, and knowledge retention, as well as their potential and advancements. Through achieving these objectives, this study will contribute to the understanding of how GBL can be used effectively to enhance dental care simulation in undergraduate education, as well as provide useful information to educators, learners, and the orthodontic community at large.[14]

This article examines the GBL process and examines whether it could be used for undergraduate education to simulate orthodontic therapy. It outlines its advantages, disadvantages, problems, and limitations. It explores the possibility and advancements in GBL approaches as well as the possible impact on engagement among learners, skill development, and information retention. Additionally, this article will discuss the applicability of GBL to undergraduate education and its potential for improving the learning experience. This investigation seeks to add to the understanding of how GBL can be utilized effectively to improve the simulations of dental care in undergraduate education, providing useful information for instructors, learners, and the broader orthodontic community by achieving these objectives.

Benefits of game-based learning

Approaches based on games have barely been effective in improving learner participation and drive in the classroom. Figure 1 and Figure 2, illustrate the development of GBL over the ages, from both educational and orthodontic points of view. Interactivity, challenge, and incentives, among other game qualities, create an immersive and fascinating learning environment that attracts learners' attention and keeps them fully engaged in the educational process.[15] GBL leverages learners' inherent curiosity and thirst for exploration by delivering educational content in the guise of a game, making learning an exciting and satisfying experience. Competition, whether against oneself or others, creates a sense of accomplishment and motivates learners to strive for progress and growth. Further, the instant feedback on development inherent in games allows learners to assess their performance, figure out areas for improvement, and experience a sense of success when they reach milestones.[16] This continuous feedback loop not only promotes learning but also creates an outlook on growth and the will to overcome challenges.[17] GBL approaches successfully stimulate active involvement, generate intrinsic motivation, and create a positive learning environment, which ultimately improves learner engagement and academic performance by leveraging the engaging characteristics of the games.[18]

GBL has emerged as an efficient means to encourage active learning and skill development.[19] GBL, as contrasted with passive learning approaches, actively engages learners in the educational process, encouraging them to participate in problem-solving, decision-making, and thinking critically.[20-23] Learners are set up with challenges, scenarios, and simulations that push them to apply their expertise and skills in realtime through interactive gameplay. As learners must analyze, make tactical choices, and tweak their strategic approach based on feedback and outcomes, this active participation stimulates more complex thinking and problem-solving competence. GBL also delivers a secure and monitored space for learners to hone and improve their skills without fear of consequences. Because the gameplay is repetitive, it enables purposeful practice, allowing learners to cultivate competency and automaticity in certain activities or procedures. Additionally, scaffolding and increasing difficulty levels are commonly employed in GBL, progressively building on learners' current knowledge and abilities to facilitate continued growth and improvement. GBL encourages learners to become fully engaged in their learning journey by integrating active learning methodologies with skill development opportunities, building important skills that can be applied to real-world circumstances, and boosting their overall competency in the subject matter.[24]

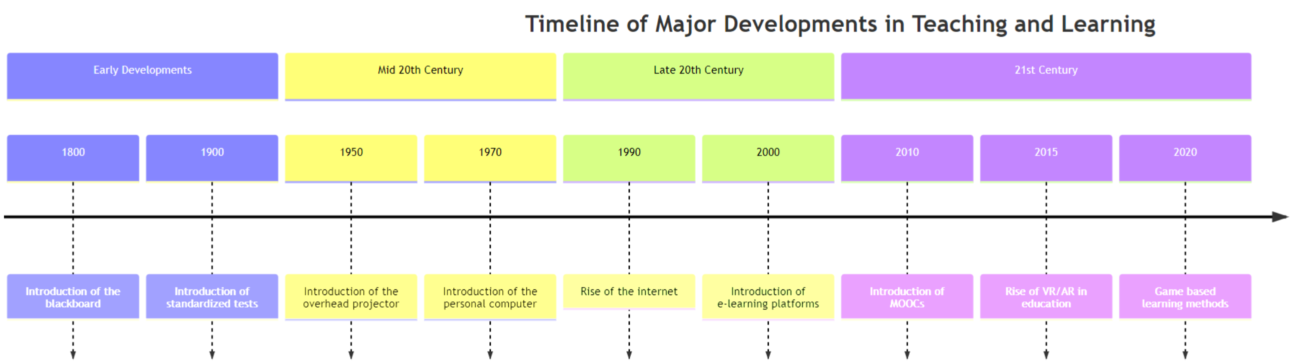

Figure 1. Timeline of major developments in teaching and learning

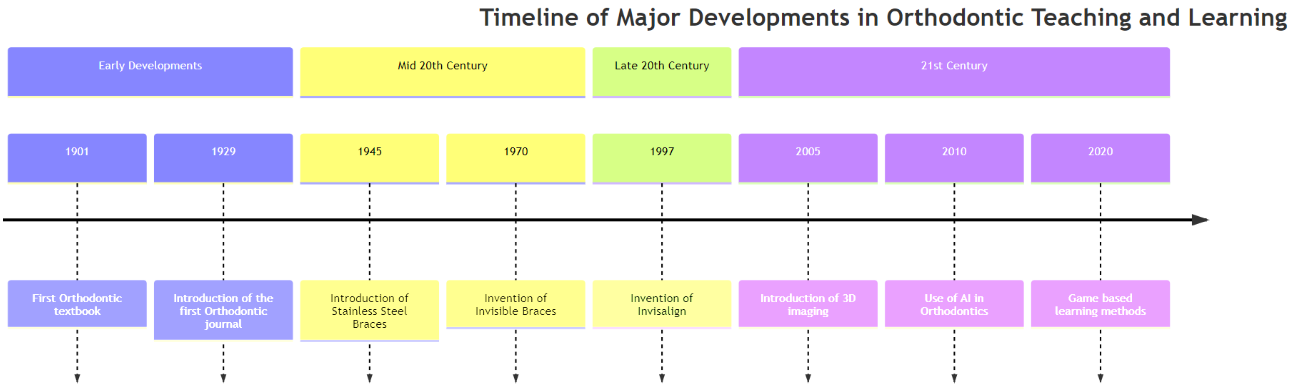

Figure 2. Timeline of major developments in orthodontic teaching and learning

Diverse game-based learning techniques for use in higher education

Virtual reality simulations

Virtual reality (VR) simulation technology has revolutionized the educational scene, enabling immersive and interactive experiences that mimic real-world settings.[25-27] VR simulations often employ the aid of a head-mounted display (HMD), that covers the user's eyes and creates a 3D virtual environment around them.[28] The HMD follows the user's head movements, offering the user a sensation of presence and immersion in the virtual environment. Hand-held controls also allow users to interact with items and modify their environment. VR simulations may generate highly detailed environments through the integration of 3D models, textures, and animations. Users may explore and interact with the simulated environment in a lifelike manner because of this degree of accuracy. Learners, for example, may observe and interact with virtual teeth, brackets, wires, and other orthodontic components in orthodontic fixed appliance therapy simulations. They will be capable of bonding brackets, bending wires, and simulating orthodontic tooth movements in real-time.

The ability to render haptic feedback is one of the primary benefits of VR simulations.[29,30] Haptic devices or gloves can be used to imitate touch and resistance, allowing users to feel the virtual objects with which they interact.[31] This feedback increases the learning process by adding a sense of reality. Learners, for example, can feel the pressure and resistance involved with changing arch wires or the tactile feedback related to stretching an elastic. VR simulations often include interactive elements and environments in addition to immersive visual and tactile sensations. Users may engage in activities, challenges, or patient scenarios that demand decision-making and problem-solving abilities. Because learners must use their knowledge and abilities in real-world circumstances, this interaction fosters active learning.

Furthermore, VR simulations enable swift feedback and assessment.[21,30] Learners can receive real-time feedback on their performance by incorporating innovative algorithms or skilled guidance, allowing them to detect imperfections, make modifications, and improve their approaches.[32] This cyclical feedback loop speeds up the learning process and allows learners to improve their abilities more quickly. In summary, VR simulation technology offers a robust and engaging platform to simulate orthodontic treatment modalities and can be aptly used as such in undergraduate dental education. Learners can engage in realistic and intriguing scenarios, refine their technical skills, and develop key decision-making abilities in a safe and controlled environment by leveraging the possibilities of VR.[33,34] The use of VR simulations in dentistry, specifically the orthodontic education curriculum, can increase active learning, improve skill development, and better prepare learners for real-world orthodontic fixed appliance therapy.[35,36]

Serious games and gamification:

Serious games and gamification have emerged as viable strategies for fostering active learning and skill development.[37] Serious games are developed with specific educational goals in mind, blending gaming features with learning content to produce compelling and interactive experiences.[38,39] These games frequently mirror real-life circumstances and obstacles related to real-life scenarios, allowing learners to use their knowledge and abilities in a real-world setting.[40] Gamification, on the other hand, involves integrating game elements into non-game scenarios to increase motivation and engagement, such as points, badges, leaderboards, and awards.[41] Learners are driven to actively participate in a dynamic and competitive learning environment when serious games and gamification are integrated into the dentistry or orthodontic curriculum. They can acquire knowledge and abilities through game-based experiential learning, problem-solving, and decision-making.[42] Competition, accomplishments, and rewards build a sense of success and drive learners to strive for ongoing development. The use of serious games and gamification in the dentistry and orthodontic curriculum encourages active learning, improves skill development, and instills a feeling of fun and drive, and this zeal can be utilized to train them in orthodontic therapies virtually.[43]

Augmented reality applications

By offering interactive and immersive learning experiences, augmented reality (AR) applications have emerged as essential tools for enhancing the undergraduate dental curriculum.[44] AR superimposes digital material over the physical world, allowing pupils to visualize and interact with virtual aspects in real-time.[45,46] AR applications can project virtual orthodontic models, diagnostic information, and treatment plans onto actual patient cases or dental manikins. This allows learners to view and manipulate virtual teeth in a highly realistic and dynamic environment, model various treatment situations, and practice orthodontic procedures.[47] AR apps encourage active learning and skill development by combining virtual and physical aspects, as learners actively engage with virtual orthodontic tools and components while receiving real-time coaching and feedback. In a controlled setting, they may hone their technique, spatial awareness, and decision-making abilities. Further, AR apps enable learners to visualize complicated ideas and anatomical features, which can increase their understanding of concepts and treatment plans. By integrating AR into an undergraduate dental curriculum, learners can participate in hands-on training, pick up practical skills, and build the skills and abilities required for successful therapies, thereby enhancing the patient's experience and their general expertise in the field.[48]

Interactive software and 3D modeling

Interactive software and 3D modeling are powerful instruments for the proactive development of skills and learning. Using 3D modeling, learners may make digital representations of all the components of oral and facial structure with amazing accuracy and precision. These models may be changed, improved, flipped, and blown in to examine new angles and viewpoints, giving learners a full understanding of morphology.[49] By adding 3D models and interactive programs into the undergraduate dental curriculum, learners actively participate in hands-on learning, boost their spatial perception, and further develop their critical thinking abilities. It teaches learners how to research complicated dental situations, make intelligent decisions, and acquire the practical skills needed to deliver successful orthodontic therapy, increasing their proficiency and trust in the field.

E-learning platforms and apps for smartphones

Smartphone apps and e-learning systems are valuable tools in undergraduate dental education, facilitating proactive learning and skill development.[50] Learners may access instructional information via mobile applications at any time as well as from any location, putting learning resources at their disposal.[51] Interactive features including assessments, instruction manuals, and simulators are used in these programs to motivate learners to solve issues and make decisions. In contrast, e-learning platforms offer chock-full online learning environments that include multimedia materials, discussion forums, and evaluation systems. Learners can engage in self-paced learning, examine course materials, and participate in collaborative conversations with classmates and instructors by incorporating mobile applications and e-learning platforms into the dentistry curriculum. These platforms additionally enable the incorporation of multimedia elements including videos, photographs, and interactive content, which aid in the learning and retention of complex dental concepts. Additionally, smartphone applications and e-learning platforms enable learners to monitor their progress, receive personalized feedback, and gain access to a wealth of educational materials beyond traditional classroom settings.

Fusion of artificial intelligence and gamified educational platforms

In the ever-evolving landscape of education, the convergence of artificial intelligence (AI) and gamified educational platforms emerges as a powerful force, reshaping traditional pedagogical approaches.[52] This symbiotic relationship promises to revolutionize how students engage with learning materials, providing adaptive, personalized experiences that cater to individual needs and preferences. The essence of this transformation lies in the creation of adaptive learning environments. Within gamified educational platforms, AI algorithms continually assess and analyze student performance in realtime. This dynamic evaluation allows for the seamless adjustment of content difficulty and pacing, ensuring that learners are presented with challenges that align with their current proficiency levels. The result is an environment where students experience an optimal learning curve, neither overwhelmed nor underwhelmed, fostering engagement and retention. Personalization is a cornerstone of the AI-gamification alliance. Machine learning algorithms embedded in these platforms comprehend individual learning styles, preferences, and areas of strength and weakness. This intricate understanding enables gamified educational platforms to tailor content, exercises, and challenges to suit each student's unique needs. The departure from the one-size-fits-all model ushers in a new era of education, where learners embark on customized educational journeys that maximize understanding and knowledge retention. Beyond personalized learning experiences, the integration of AI into gamified platforms offers educators and institutions a trove of data-driven insights. These platforms generate comprehensive information on student performance, engagement levels, and areas of struggle.

Educators can harness this data to identify pedagogical gaps, refine teaching strategies, and implement targeted interventions. The result is an educational ecosystem that is more informed and responsive, adapting to the evolving needs of students.

Central to the AI-gamification synergy is the role of machine learning in adaptive assessments. Traditional assessments often fall short of capturing the nuances of individual learning journeys. Machine learning algorithms enable the creation of adaptive assessments that evolve based on a student's responses. This approach ensures a more accurate and comprehensive evaluation, assessing not just memorization but also critical thinking, problem-solving skills, and the application of knowledge in real-world scenarios. However, the integration of AI into gamified educational platforms is not without its challenges and ethical considerations. The extensive collection and utilization of student data raise concerns about privacy, data security, and the potential for algorithmic bias. Robust frameworks and guidelines are essential to address these issues, ensuring that the benefits of AI in education are realized without compromising ethical standards. As we contemplate the future, the trajectory of AI in gamified education appears poised for even greater advancements. Ongoing research and development efforts focus on refining algorithms, improving adaptability, and addressing ethical concerns. The continued evolution of this symbiotic relationship holds the potential to not only enhance the learning experience for individual students but also contribute to the broader field of education through the generation of insights and innovations. The fusion of AI and gamified educational platforms represents a transformative force that propels pedagogy into a dynamic and responsive era, where education becomes a truly personalized and engaging journey for each learner.

Blockchain's impact on gamified credentialing and certification in orthodontic education

In the age of digital innovation, the integration of blockchain technology into the field of education has introduced exciting opportunities for gamified credentialing and certification.[53] Blockchain, primarily known for its role in secure and transparent transaction systems like cryptocurrencies, is now making inroads into education, particularly in the context of orthodontic education. This discussion delves into the transformative potential of blockchain in gamified credentialing, exploring how it can revolutionize the way orthodontic professionals acquire and showcase their expertise. Blockchain technology, often referred to as a distributed ledger, has gained prominence due to its capacity to provide secure and tamper-proof records of transactions. In the context of education, blockchain presents a promising avenue for credentialing and certification, ensuring the authenticity and permanence of academic achievements.

Traditionally, orthodontic education and certification have relied on paper-based or centralized digital systems to verify the qualifications of professionals. These systems, while functional, are not without their limitations. The process of verifying certificates and credentials can be time-consuming and susceptible to errors or fraud. Moreover, professionals often find it challenging to present a comprehensive and easily accessible portfolio of their qualifications. Blockchain technology addresses these limitations by providing a decentralized and immutable platform for recording and verifying academic achievements. In the context of orthodontic education, this means that credentials, certificates, and achievements can be securely stored on the blockchain, creating a digital "ledger of learning."

Immutable records: Blockchain records are immutable, meaning that once a credential is added to the blockchain, it cannot be altered or deleted. This feature ensures the permanence and integrity of orthodontic qualifications.

Decentralization: The decentralized nature of blockchain eliminates the need for a central authority to verify credentials. Orthodontic professionals can directly share their blockchain-verified credentials with employers, colleagues, and patients, streamlining the verification process.

Enhanced transparency: Transparency is a hallmark of blockchain technology. Anyone with access to the blockchain can verify the authenticity of a credential, promoting trust in the orthodontic education system.

Portability: Blockchain-verified credentials are portable and can be easily shared across platforms and institutions. Orthodontic professionals can maintain a digital portfolio of their achievements, making it convenient to showcase their qualifications to prospective employers or patients.

The integration of gamification into orthodontic education has already proven to be a valuable pedagogical tool. Gamified learning modules engage students and create interactive, immersive experiences. Students in orthodontic programs can earn badges, complete challenges, and demonstrate their skills through gamified assessments. These achievements, when stored on the blockchain, become part of their verifiable credentials.

The synergy between blockchain technology and gamified credentialing in orthodontic education opens several possibilities:

Dynamic skill validation: Orthodontic professionals can continuously update their blockchain-verified credentials as they acquire new skills and knowledge. Gamified assessments and achievements serve as real-time indicators of their expertise.

Trust and assurance: Patients seeking orthodontic care can verify the credentials of their providers with ease and confidence. The immutable nature of blockchain records ensures trust in the qualifications of orthodontic professionals.

Innovation in assessment: Gamified assessments in orthodontic education can be designed to align with industry standards and evolving best practices. These achievements, recorded on the blockchain, reflect the latest advancements in the field.

Competitive edge: Orthodontic professionals can gain a competitive edge in the job market by showcasing their gamified credentials on the blockchain. Employers can easily identify candidates with the most up-to-date and relevant skills.

While the potential of blockchain-powered gamified credentialing in orthodontic education is immense, it is not without challenges and considerations.

Security: Ensuring the security of blockchain-based credentials is paramount. Robust cybersecurity measures must be in place to protect the integrity of the blockchain network.

User adoption: Widespread adoption of blockchain technology in orthodontic education will require education and training for both educators and professionals.

Standardization: Establishing standardized protocols for blockchain credentialing is essential to ensure compatibility and interoperability across institutions and platforms.

The emergence of blockchain technology in the context of gamified credentialing and certification represents a significant advancement in orthodontic education. By providing immutable, decentralized, and transparent records of achievements, blockchain enhances the trust and credibility of orthodontic qualifications. When combined with gamification, this technology creates a dynamic, real-time representation of orthodontic professionals' expertise, offering benefits to educators, employers, and patients alike. As the synergy between blockchain and gamified credentialing continues to evolve, it holds the promise of transforming orthodontic education and professional validation in unprecedented ways.

Collaborative learning experiences

Collaborative learning experiences have long been recognized as a powerful pedagogical approach, fostering interaction, critical thinking, and knowledge sharing among students.[54] In recent years, the integration of gamification into collaborative learning environments has added a new dimension to this educational strategy. One of the central tenets of gamification in collaborative learning is the creation of a gamified ecosystem where students actively engage with course materials and interact with their peers. This engagement is facilitated through various game-like elements, such as points, badges, leaderboards, and team-based challenges. These components transform the learning process into an interactive and competitive endeavor, encouraging students to collaborate, communicate, and problem-solve together.

In orthodontic education, this gamified collaborative approach can be particularly beneficial. Orthodontics involves intricate procedures and decision-making that often require a multifaceted perspective. By integrating gamification, students can work together in teams to diagnose cases, plan treatment strategies, and discuss clinical scenarios. These collaborative efforts mirror real-world clinical practice, where interdisciplinary teamwork is crucial for comprehensive patient care. Moreover, gamified collaborative learning experiences in orthodontics can simulate the complexities of patient cases and treatment planning. Students can be presented with virtual patient profiles, each with unique orthodontic challenges. They must collaborate within their teams to devise treatment plans, select appropriate orthodontic appliances, and anticipate potential complications. These interactive scenarios not only reinforce clinical knowledge but also promote critical thinking and decision-making skills.

Incorporating competition into the gamified collaborative learning environment can further enhance student engagement and motivation. Orthodontic programs can implement leaderboards or point systems to track team performance. Healthy competition can inspire students to actively participate, contribute their insights, and strive for excellence in their collaborative efforts. This element of competition, when balanced with cooperation, creates a dynamic learning atmosphere that mirrors the demands of the orthodontic profession. Additionally, gamification allows for immediate feedback and assessment. As students collaborate on patient cases or treatment planning, the gamified system can provide instant feedback on their decisions. This feedback loop reinforces learning and allows students to learn from their mistakes in a low-risk virtual environment. It also encourages continuous improvement and reflection, which are essential qualities for future orthodontic practitioners. Another advantage of gamified collaborative learning experiences is the ability to scale education. In traditional clinical settings, hands-on training and patient interaction may be limited by resource constraints. Gamification offers a scalable solution, allowing students to engage in collaborative learning experiences regardless of physical limitations. Virtual patient cases and simulations can be accessed from anywhere, enabling students to practice and refine their skills at their own pace. While the benefits of gamified collaborative learning in orthodontic education are evident, it's important to acknowledge potential challenges and considerations. Effective implementation of gamification requires careful planning, curriculum design, and technology infrastructure. Faculty training may be necessary to facilitate and guide the collaborative learning process effectively. Additionally, ensuring that the gamified elements align with educational objectives and orthodontic competencies is crucial.

Table 1 compares all the technologies available for use in GBL for orthodontic learning. GBL techniques have significant potential to improve orthodontic education. Educators may utilize these technologies to create simulated environments that closely resemble real-world orthodontic scenarios, allowing learners to import all the necessary components to simulate unique circumstances observed in clinical environments during orthodontic operations. In these simulated settings, learners may visualize and engage with virtual patients, analyze diagnostic data, and design entire treatments. In a safe and regulated setting, they may obtain hands-on experience by conducting tasks like bracket insertion, wire modifications, and visualizing tooth movement. The use of these GBL tactics results in an engaging and immersive learning environment that promotes active participation, enhancement of skills, analytical thinking, and decision-making ability. Learners may get instant feedback, monitor their progress, and fine-tune their tactics, resulting in enhanced proficiency and confidence in executing fixed orthodontic therapy. These technologies connect academic information to actual use, equipping learners for real-world situations while also enhancing patient outcomes. GBL techniques, in general, provide an original perspective to orthodontic training by allowing learners to engage with simulated patients, construct treatment strategies, and carry out comprehensive orthodontic procedures in a virtual environment.

Challenges and Limitations

While GBL offers immense potential to improve education, its progress may be hampered by the expensive cost of development and technological restrictions. Creating instructional games and simulations involves tremendous time, skill, and financial input. The creation of high-quality interactive material necessitates the experience of game developers, instructional designers, and subject matter experts. Furthermore, the technical requirements for deploying GBL systems, which include specialized hardware, software, and network infrastructure, might be challenging. The requirement for robust systems to handle visual rendering, interaction, and real-time feedback can present challenges, especially for institutions with limited funds or obsolete technical infrastructure. Furthermore, the rapid improvements in gaming technology demand ongoing upgrades and maintenance to keep up with new platforms and customer expectations. These obstacles may stymie the broad acceptance and use of GBL in educational contexts. Collaborations among educators, developers, and institutions, as well as cost-effective solutions and technological breakthroughs, can help reduce these issues and increase the accessibility and efficacy of GBL techniques.[55]

Because of the necessity for alignment with established educational frameworks, incorporating GBL into existing orthodontic curricula could pose obstacles.[56] Orthodontic programs frequently follow well-defined curricula that adhere to learning objectives and accreditation criteria. To guarantee that learning goals are fulfilled, and educational standards are followed, integrating GBL needs careful analysis and alignment with the current curriculum. Traditional teaching techniques may need to be modified to accommodate GBL approaches, which may necessitate changes to course design, evaluation systems, and faculty training. Integration attempts might also be hampered by resistance to change and concerns about the perceived efficacy and legitimacy of GBL. Furthermore, limited instructional time and conflicting goals within the curriculum might make devoting adequate time and resources to implement GBL activities difficult. To address these problems, educators, instructional designers, and administrators must work together to identify suitable integration points, provide supportive infrastructure, and create opportunities for faculty growth. The incorporation of GBL may be successfully applied by carefully negotiating these hurdles, enriching orthodontic education, and better preparing learners for

Table 1. Comparison chart highlighting the relevance of various game-based learning technologies

Game-based learning technology	Relevance to game-based learning
Virtual reality (VR)	Immersive experiences that simulate real-world scenarios, enhancing engagement and presence. Enables students to practice skills and interact with virtual patients.
Augmented reality (AR)	Overlays virtual content onto the real world, allowing learners to visualize and interact with orthodontic components and procedures in real time. Facilitates contextual learning and hands-on experience.
Serious games	Purpose-built games designed for educational objectives, integrating orthodontic concepts into gameplay. Offers interactive and engaging learning experiences while promoting knowledge acquisition and skill development.
Interactive games	Interactive games that encourage active participation and problem-solving. They provide immediate feedback, fostering critical thinking and decision--making skills in an enjoyable and engaging manner.
Mobile phone games	Portable and accessible games that can be utilized for on-the-go learning. Offers convenience, engagement, and quick access to orthodontic educational content, reinforcing learning outside the classroom.

Each of these game-based learning tools contributes something unique to the field of orthodontic education. Serious Games give focused instructional material, Interactive Games stimulate active learning and problem-solving, and Mobile Phone Games provide flexibility and accessibility. The technology used is determined by the targeted learning goals, the accessible resources, and the unique educational situation.

real-world practice.

The standardization of simulation scenarios might present challenges and limitations in integrating GBL[57] consistency and uniformity across multiple simulation settings is critical for successful educational results in the field of orthodontic education. Standardization aids in the establishment of benchmarks, norms, and objectives that are consistent with educational objectives and professional standards. Incorporating GBL strategies, on the other hand, frequently necessitates the creation of customized simulation scenarios adapted to distinct learning objectives and ability levels. This can result in differences in content, difficulty levels, and evaluation standards between educational institutions or programs. Lack of standardization can lead to disparities in learner learning experiences and make educational results difficult to compare. Furthermore, the creation and validation of standardized simulation scenarios necessitate collaboration among subject matter experts, instructional designers, and researchers, which may be time-consuming and resource-intensive. Overcoming this difficulty will necessitate the development of industry-wide norms, collaboration among schools, and continuous research to create standardized simulation scenarios that successfully satisfy the educational objectives of orthodontic learners. By solving the standardization issue, GBL may be more broadly and successfully integrated into orthodontic education, improving learner learning experiences and preparing learners for professional practice.

User experience and interface design are critical to the effective integration of GBL, but they can be equally challenging.[58] User demands, preferences, and technology limits must all be carefully considered when designing intuitive and engaging user interfaces that promote effective learning experiences. To increase user engagement, GBL platforms should include fluid navigation, clear instructions, and interactive aspects. Striking a balance between instructional information and gaming mechanics, on the other hand, might be difficult. Because orthodontic principles and procedures are complicated, comprehensive explanations and images may be required, affecting the game's usability and overall user experience. Furthermore, interface design is complicated by varied learner groups with varying degrees of technical skill and learning styles. It is critical to provide accessible, inclusive, and adaptable interfaces that cater to various learning preferences and abilities. To overcome these issues, collaboration between instructional designers, game developers, and educators is essential. GBL may overcome these restrictions by emphasizing user experience and interface design and providing learners with immersive, intuitive, and effective teaching experiences in orthodontics.

The incorporation of GBL in orthodontic education could encounter barriers in terms of validation and evidence-based efficacy.[59,60] It is critical, like with any educational strategy, to guarantee that GBL approaches are successful, dependable, and backed by empirical data. To establish the influence of GBL on learner learning outcomes, the validation process includes rigorous testing, evaluation, and research. This necessitates the gathering of quantitative and qualitative data to assess the success of the instructional games, simulations, or platforms employed. Conducting large-scale investigations and achieving statistically meaningful findings might take an extended amount of time and an extensive number of resources. Furthermore, the ever-changing gaming scene and the dynamic nature of technology require continual review and upgrading of GBL interventions. Collaborations among academics, educators, and game producers are essential for establishing strong evidence for the usefulness of GBL in orthodontic education. By addressing these issues and encouraging evidence-based practice, GBL can gain credibility, demonstrate its positive influence on learning outcomes, and achieve greater recognition in the field of orthodontics.

Future directions

Technological and hardware advancements have considerably aided in the development and enhancement of GBL. As technology advances, novel prospects for immersive and interactive educational experiences emerge. More powerful gear, such as high-performance graphics cards and VR headsets, makes realistic and aesthetically beautiful simulations conceivable. This allows learners to interact with virtual worlds that are analogous to real-world circumstances. Furthermore, the advent of AR and VR technology has transformed the educational scene, allowing for hands-on learning and realistic simulations. These technological and hardware improvements make it easier to include GBL in orthodontic education by offering the essential tools and platforms for creating interesting and successful learning experiences. As technology advances, so will the creation of GBL, which will improve learner engagement, interaction, and learning outcomes in orthodontics.

Adaptive simulations and personalized learning are emerging as significant tools for advancing GBL.[61] There is no doubt that learners' demands, preferences, and levels of expertise differ from one another. Individuals can customize their educational experiences by utilizing personalized learning techniques and having access to knowledge and challenges that are suited to their specific skill sets and learning styles. An adaptive simulation takes personalization a step further by dynamically changing the complexity level and material based on the progress and success of the learner. This tailored approach enhances learner engagement, motivation, and understanding of orthodontic concepts and competencies. Learners can receive real-time feedback, customized interventions, and personalized concepts via adaptive exercises, allowing them to focus on areas that need development and advance at their own pace. In addition, collecting and analyzing learner information across GBL contexts allows educators to get insights into how learners perform and adjust their teaching tactics accordingly. Personalized lessons and adaptive simulations can change orthodontic education by providing individualized and adaptive experiences that optimize learning outcomes for all learners as they grow.

Teamwork and multiplayer interactions are essential for the growth of GBL.[62-64] These elements promote social connection, communication, and cooperation, all of which are important in the field of orthodontics. Learners may participate in group activities, work together to solve challenges, and discuss ideas and viewpoints by adding collaborative components to GBL. This collaborative environment mimics real-life circumstances in which orthodontic practitioners frequently engage with colleagues, specialists, and other health care professionals. Furthermore, multiplayer activities foster competition and collaboration, which boosts learner motivation and engagement. Through collaborative problem-solving, learners may learn from one another, share knowledge, and improve their critical thinking and decision-making abilities. The inclusion of multiplayer aspects also allows for real-time engagement, feedback, and discourse, fostering a feeling of community and an enjoyable learning environment. Via collaboration and multiplayer experiences, GBL encourages active participation, collaboration, and the acquisition of interpersonal skills, finally equipping learners with the collaborative spirit of orthodontic practice.

Integrating AI and machine learning offers the potential to dramatically accelerate GBL advancement.[65] Machine learning and AI algorithms can analyze huge amounts of data collected during games, providing adaptive and personalized learning experiences. These tools can monitor learner progress, identify points of weaknesses and strengths, and provide personalized feedback and solutions. Systems powered by AI may also dynamically change the game's complexity, speed, and content to optimize outcomes for learning for individual learners. Moreover, AI and machine learning may enhance the intellect of digital avatars or simulated patients, resulting in more realistic and entertaining interactions. Such tools can also aid in automated evaluation, relieving teachers' workload and offering learners immediate feedback. By combining AI and ML, GBL can continuously adapt and develop, tailoring the learner's process to the specific requirements of each learner. As AI and machine learning continue to evolve, their combination with GBL has the potential to significantly improve learner engagement, personalization, and the overall efficacy of orthodontic education.

GBL has the potential to have a long-term influence on orthodontic teaching and patient results. GBL can improve learners' knowledge retention, critical thinking skills, and clinical decision-making abilities by presenting them with engaging and immersive experiences.[66] Learners can build experience and competency in orthodontic operations through regular practice and exposure to a variety of circumstances. As learners join clinical practice, this can lead to better patient outcomes. Learners may replicate the full process of fixed orthodontic therapy, from patient evaluation and treatment planning through appliance placement and adjustment, using GBL. By providing a secure and controlled setting, learners may obtain hands-on experience, fine-tune their methods, and learn from mistakes without jeopardizing the safety of actual patients. The gamification of these learning experiences encourages engagement, motivation, and self-directed learning, all of which are important characteristics for lifelong learning in the continually expanding field of orthodontics. In the end, the long-term influence of GBL on orthodontic training can result in better-prepared orthodontists, better treatment results, and higher patient satisfaction.

Conclusion

GBL approaches have the potential to completely transform orthodontic education and training. Table 2 gives a comparison between traditional teaching methods and GBL. Traditional teaching approaches frequently focus on passive listening and little learner interaction, which results in lower motivation and retention. GBL, on the other hand, encourages active involvement, immersive experiences, and intrinsic motivation through gamification, resulting in increased learner engagement, information retention, and skill development. GBL produces dynamic and interesting educational experiences by using the potential of virtual simulations, AR, personalized learning, teamwork, and technological breakthroughs. These techniques not only improve learner engagement, motivation, and active learning, but they also help with skill development, critical thinking, and decision-making. Learners can view, engage with, and practice comprehensive orthodontic therapy in virtual environments that mimic real-life circumstances when GBL is integrated into the undergraduate dentistry curriculum. Learners may gain knowledge, enhance patient outcomes, and prepare for the intricacies of orthodontic practice by participating in these immersive activities. To fully exploit the potential of GBL, however, problems such as development costs, integration with current curricula, validation, user interface design, and standardization of simulation scenarios must be addressed. Collaboration between educators, researchers, and game makers will be critical as the area evolves to establish evidence-based practices and assure the efficacy and legitimacy of GBL techniques. Embracing these novel

Table 2. Comparison chart: traditional teaching methods vs. game-based learning in orthodontic education

Aspect	Traditional teaching methods	Game-based learning
Student engagement	Passive listening and limited interaction	Active participation and immersive experiences
Motivation	Varied, often reliant on external factors	Intrinsic motivation through gamification
Knowledge retention	Rote memorization and limited retention	Enhanced retention through interactive gameplay
Skill development	Theoretical understanding with limited practice opportunities	Hands-on practice in simulated orthodontic scenarios
Critical thinking	Limited opportunities for critical thinking and problem-solving	Encourages critical thinking through challenges and decision-making
Personalized learning	Limited adaptability to individual student needs	Tailored learning experiences based on individual progress
Real-world application	Limited exposure to real-world orthodontic scenarios	Simulates real-world orthodontic cases for practical application
Collaborative learning	Limited opportunities for collaboration and teamwork	Promotes collaboration through multiplayer experiences
Immediate feedback	Delayed feedback from instructors	Immediate feedback on performance and decision-making
Student motivation and satisfaction	Varies, often influenced by external factors	Increased motivation and satisfaction through gamified learning experiences

This comparison chart showcases the key differences between traditional teaching methods and game-based learning in orthodontic education. It emphasizes the advantages of game-based learning, such as increased engagement, motivation, knowledge retention, skill development, critical thinking, personalized learning, real-world application, collaboration, and immediate feedback.

instructional tools will influence the future of orthodontic training, enabling the next generation of orthodontists to provide great patient care and leave a lasting impression in the field.

Competing Interests

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Ethical Approval

Not applicable.

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