Innovative Knowledge Practices in Technology-Enhanced Learning

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| abstract

In recent years, the integration of gamification and adaptive learning technologies has gained significant traction within educational contexts, offering new avenues for enhancing learner engagement, tailoring instruction, and supporting cognitive development. This narrative review investigates the interplay between these two approaches, examining how their combined use can facilitate the management of cognitive load, strengthen intrinsic motivation, and promote cognitive flexibility. The analysis draws upon scholarly articles published since 2010, identified through databases such as PubMed, Scopus, and Google Scholar. Particular attention is given to the pedagogical implementation of game-based strategies – such as immediate feedback, reward mechanisms, and competitive dynamics – in conjunction with adaptive systems that adjust learning content through algorithmic insights into student behavior. The evidence suggests that gamification can foster learner autonomy and sustained interest, while adaptive technologies fine-tune instructional delivery by calibrating task complexity to individual learner profiles. This alignment contributes to more efficient cognitive processing and encourages flexible problem-solving strategies. The effectiveness of these methods is further amplified through the use of immersive media, including Augmented and Virtual Reality, which provide contextualized learning experiences and reduce superfluous cognitive demands. Although these innovations present considerable promise, the review also highlights the importance of intentional design to prevent overreliance or unintended cognitive strain. Overall, the findings underscore the pedagogical value of integrating adaptive systems and gamified elements and emphasize the need for continued research into their long-term educational impact.

DOI 10.36158/97912566920713

1. Introduction

In recent years, digital education has undergone a profound transformation, driven by the emergence of innovative technologies that are reshaping both teaching and learning practices. The widespread adoption of e-learning platforms, interactive digital tools, and algorithm-driven adaptive systems has significantly broadened access to education and enabled more personalized learning experiences, addressing many of the limitations associated with traditional instruction (Redecker, 2017). Among the most influential innovations within the broader field of Technology-Enhanced Learning (TEL; Mayer, 2009) are adaptive learning and gamification, both of which have

shown particular promise in enhancing personalization and learner engagement. Adaptive learning harnesses intelligent algorithms to monitor student performance in real time and deliver content tailored to individual needs, thereby improving instructional effectiveness (Uktamova & Ruzmetova, 2025). In parallel, gamification incorporates playful elements – such as digital badges, progress tracking, and leaderboards – to boost motivation and promote sustained engagement, with positive results documented in both K–12 and higher education settings (Duterte, 2024). While each approach has demonstrated clear benefits when applied independently, recent studies have begun to explore their combined use to further enrich the learning experience. Emerging evidence suggests that integrating adaptive learning and gamification within well-designed TEL frameworks can enhance personalization while preserving high levels of learner motivation and participation (Bennani & Maalel, 2022; Borotić & Jagušt, 2022).

However, the effects of this integration on cognitive processes and long-term learning outcomes remain an open area of investigation. This narrative review aims to examine the primary benefits, challenges, and future directions associated with the combined implementation of adaptive learning and gamification in contemporary digital education.

2. Gamification Strategies for Sustained Engagement

Gamification is defined as «the use of game design elements and game principles in non-game contexts» (Deterding, Dixon, Khaled, & Nacke, 2011). Gamification incorporates elements such as points, badges, and leaderboards to stimulate user engagement and motivation across various application areas. In education, gamification is intended to enhance learning by making tasks more interactive and rewarding. When effectively implemented, it bridges game mechanics and real-world goals to enrich user experience and performance.

Feedback is a crucial aspect of gamification. In educational or work contexts, it offers immediate information regarding user performance, allowing students and employees to quickly understand areas of success and those needing improvement. For instance, applications like Duolingo provide instant feedback to users learning a language. When a user answers correctly, they receive a positive sound or an encouraging message; when they make a mistake, corrective feedback is provided to help them improve.

Competition represents another significant lever of gamification. It is based on the natural desire to measure oneself against others to gain recognition. Competition is often incentivized through leaderboards that display the highest scores. In online courses like those offered by Coursera, students can view their rankings, encouraging them to constantly improve to surpass their peers.

Rewards are fundamental tools used in gamification to motivate users to complete tasks or achieve goals. These can vary, ranging from external rewards (points, badges, physical prizes) to internal ones (personal satisfaction). Rewards help maintain high motivation and make the experience more engaging. Platforms like Khan Academy award badges to students when they complete activities or reach competency levels, serving as symbols of progress and contributing to engagement. Although not physical prizes, these badges help maintain high student engagement. When discussing rewards, it is important to distinguish between intrinsic motivation – the drive to engage in an activity

DOI 10.36158/97912566920713

for its inherent satisfaction or interest – and extrinsic motivation, which refers to behavior driven by external rewards such as grades, recognition, or money (Ryan & Deci, 2000).

In education, external rewards, when overused, enhance extrinsic motivation (Ryan & Deci, 1985) and diminish interest in the activity itself (Deci & Ryan, 1980). However, intrinsic motivation is definitively more critical for deep and sustained learning. Thus, achieving a balanced integration of intrinsic motivation and incentives is essential for fostering meaningful engagement and learning (Ryan & Deci, 1985). Gamification, in general, helps students become more intrinsically motivated (Deterding, Dixon, Khaled, & Nacke, 2011). This means that students are driven to participate and engage in activities not just to obtain external rewards or recognition, but because they feel a sense of personal satisfaction and accomplishment (Csikszentmihalyi, 1990). Challenges are faced with enthusiasm and commitment because students want to demonstrate their skills and abilities simply for the pleasure of doing so (Pink, 2009). Gamification can significantly enhance intrinsic motivation, provided it is designed to meet fundamental psychological needs. According to self-determination theory, these needs include competence, autonomy, and a sense of achievement. When these elements are thoughtfully integrated into gamified learning environments, they foster sustained engagement and deeper cognitive processing. One of the primary mechanisms through which gamification stimulates intrinsic motivation is the perception of competence. Learners are more motivated when they engage in tasks that challenge their abilities and allow them to demonstrate meaningful progress. Gamified systems often include activities that require effort, skill development, and strategic thinking. The resulting satisfaction is not derived from earning points or badges, but from mastering the content and observing tangible improvement. For instance, in a language learning app, users may be motivated to complete complex exercises to improve fluency, rather than simply to collect rewards (Werbach & Hunter, 2012; Bunchball, 2010). A second key factor is autonomy, understood as the ability to exert control over one's learning process. Games typically offer players the freedom to choose how to approach challenges, and this principle translates effectively into educational contexts. When learners are given the opportunity to select tasks, personalize learning paths, or regulate their own pace, they develop a sense of ownership over their progress. In gamified corporate training programs, for example, employees who can navigate flexible and adaptable activities report higher levels of satisfaction and engagement (Hamari, Koivisto & Sarsa, 2014; Nicholson, 2015). Autonomy also supports self-regulated learning and contributes to the development of metacognitive skills. Another important mechanism involves recognition and the sense of achievement. Although external rewards are often associated with extrinsic motivation, they can reinforce intrinsic motivation when designed to acknowledge genuine effort and progress. Badges, points, and milestones – when linked to meaningful accomplishments – serve as symbolic affirmations of competence and perseverance. A fitness app that awards badges for goals such as "10,000 steps a day" illustrates how recognition can validate effort and strengthen internal motivation. In educational settings, similar mechanisms can enhance learners' confidence and persistence (Khaleel et al., 2016; Anderson & Dill, 2000). Despite its potential, gamification must be carefully calibrated. Excessive emphasis on external rewards may shift learners' attention away from the intrinsic value of the activity, leading to reduced engagement over time. In contrast, strategies that emphasize meaningful challenges, autonomy, and personalized feedback are more effective in sustaining intrinsic motivation and promoting deep learning (Hanus & Fox, 2015; Lee & Hammer, 2011; Seaborn & Fels, 2015). This balance is particularly important in diverse

DOI 10.36158/97912566920713

educational contexts, where learners' motivational profiles and cognitive needs vary. A well-designed gamified system should therefore integrate motivational elements that support long-term engagement, self-efficacy, and meaningful learning outcomes.

3. Adaptive Learning and Individual Needs

Adaptive learning refers to the personalization of the learning process through the dynamic adjustment of cognitive load to align with an individual's cognitive capacity, thereby promoting more efficient and effective learning. Cognitive load is defined as the amount of mental energy and effort required for new information to be properly understood and retained (Sweller, 1988). A core strategy in personalizing cognitive load involves adapting instructional content and pacing to the learner's needs, while supporting the learner's ability to regulate cognitive demands effectively (Sweller, Ayres, & Kalyuga, 2011). This approach ensures that new content is appropriately matched to the learner's prior knowledge and current level of competence (Ayres & Sweller, 2014). Adaptive learning systems track students' progress by collecting data on their performance and delivering personalized feedback in real time (Nicholson, 2015). In doing so, these technologies support individualized learning trajectories and provide targeted assistance based on a learner's evolving needs. Recent advancements in data analytics and machine learning have made adaptive learning systems not only possible but also highly practical, transforming theoretical concepts into scalable educational solutions (Hamari, Koivisto, & Sarsa, 2014). These systems have greatly benefited from AI-based technologies, which allow for the real-time modification of learning materials and the provision of individualized suggestions and feedback. When implemented effectively, such dynamic adaptations help sustain student motivation and engagement throughout the learning process. This approach also contributes to reducing cognitive effort and enhancing cognitive flexibility, defined as the ability to adapt one's thinking and behavior in response to changing circumstances or novel problems (Brown, 2020). AI-powered systems can deliver highly personalized, specific, and timely feedback tailored to each student's abilities. As Zhou et al. (2024) emphasize, «providing feedback as quickly as possible is crucial for improving students' academic performance». These systems analyze student interactions and provide insights that help learners identify their weaknesses and refine their learning strategies. Beyond managing cognitive load, this technology simplifies the learning process by identifying and addressing problem areas, adjusting instructional depth and scope, and supporting opportunities for individualized practice (Skulmowski & Xu, 2022). As a result, students receive appropriately calibrated support and challenges aligned with curriculum requirements. Smart Sparrow, Knewton, Carlson Learning, and Squirrel AI are prominent examples of adaptive learning platforms (Smart Sparrow, 2018; Knewton, 2017). Knewton analyzes learner behaviors – such as accuracy and time spent on tasks – to dynamically modify instructional sequences. It offers supplemental materials or targeted exercises when a student struggles, ensuring a responsive learning pathway (Sweller, Ayres, & Kalyuga, 2011). Similarly, Smart Sparrow adapts content and feedback based on real-time session data, identifying learning gaps and providing tailored resources (Smart Sparrow, 2018). Carlson Learning uses performance analytics to adjust instructional materials and activities in real time, adapting both difficulty and type of exercises to meet each learner's needs. Squirrel AI employs artificial intelligence algorithms to assess student comprehension on an ongoing basis,

DOI 10.36158/97912566920713

generating individualized learning plans with personalized resources and improvement strategies. While adaptive systems are designed to reduce cognitive load, their success depends on accurate interpretation of learner needs. If algorithms misjudge performance, the result may be mismatched content that increases cognitive strain. Lessons may become either too simple or too difficult, leading to disengagement or confusion (van Merriënboer & Sweller, 2005). Overly advanced materials can overwhelm learners, while content that is too basic may fail to stimulate engagement, ultimately undermining learning outcomes.

4. Cognitive Flexibility as a Core Outcome of Adaptive Learning and Gamification in Technology-Enhanced Education

Within the framework of educational technologies such as adaptive learning and gamification – which are designed to manage cognitive load by adjusting content difficulty and incorporating motivational elements like rewards and challenges – cognitive flexibility emerges as a critical outcome. This mental agility enables learners to shift strategies dynamically in response to varying instructional demands, complementing cognitive load management by allowing smooth transitions between problem-solving approaches without triggering overload. As learning environments become more complex and personalized, the ability to alternate cognitive strategies is increasingly vital. Cognitive flexibility is indispensable because different challenges require different modes of thinking. These mental shifts must occur seamlessly, without disrupting cognitive flow. As Miller (2021) notes, «an individual should have the ability to switch between different cognitive strategies and perceptions of their difficulties». Enhancing this ability not only improves adaptability but also strengthens problem-solving capacity, a fundamental skill across all domains of learning and life. Game-based learning and adaptive technologies contribute significantly to developing cognitive flexibility in a wide range of learners. According to Gee (2003), «if educational games stimulate inquiry, experimentation, and strategic thinking, then these are the skills that develop». Many of the most effective games incorporate evolving puzzles that require players to modify their thinking patterns over time. One compelling example is *Portal 2*, a puzzle-platform videogame developed by Valve Corporation. Through the use of a "portal gun" that allows users to navigate space nonlinearly, players must continuously reformulate strategies to solve increasingly complex challenges. This interactive and immersive environment fosters creative thinking and sustained cognitive engagement, directly supporting the development of cognitive flexibility.

Modern educational technologies build upon this foundation by offering tools that are both engaging and cognitively enriching. Recent innovations showcased during the UM Education Days 2025 illustrate the potential of AI tutors to transform problem-based learning (PBL) through the use of generative AI. These systems provide personalized content, encourage critical thinking, and enhance student engagement, all while raising important ethical considerations (Maastricht University, 2025a; 2025b). Initiatives supported by EDLAB grants further expand AI applications in assessment, coaching, and academic writing, promoting individualized learning pathways and increasing intrinsic motivation (Maastricht University, 2024a). However, these advancements also raise a hypothesis of concern: while AI can enhance personalization and engagement, it may simultaneously pose a risk of learner over-dependence, potential-

DOI 10.36158/97912566920713

ly diminishing autonomous cognitive flexibility. The integration of immersive digital tools such as Augmented Reality (AR) and Virtual Reality (VR) offers further promise. AR enriches traditional instruction by superimposing digital content onto physical environments, facilitating contextual interaction and spatial reasoning. VR, by contrast, provides full immersion, enabling learners – particularly in technical disciplines like medicine and engineering – to simulate high-stakes tasks in risk-free environments (Mikropoulos & Natsis, 2011). When thoughtfully implemented, these technologies can reduce extraneous cognitive load by translating abstract concepts into interactive, multisensory experiences (Zheng & Warschauer, 2015). Looking to the future, AR, VR, and emerging technologies may redefine how knowledge is accessed, explored, and understood in educational settings. However, their effectiveness depends on thoughtful instructional design that respects cognitive boundaries. Poorly aligned or overly complex experiences may inadvertently increase cognitive load and undermine learning outcomes. As such, continued experimentation and rigorous empirical research will be essential to fully harness the educational potential of immersive learning tools while mitigating their limitations (Liu & Chen, 2015).

5. Gamification and Adaptive Technology: The Maastricht University Case Study

Maastricht University exemplifies an advanced and well-structured model of Technology-Enhanced Learning (TEL) in higher education, particularly within its medical curriculum. The institution effectively combines adaptive learning and gamification within a Problem-Based Learning (PBL) framework (Mayer, 2001; Clark, 2009), where students work collaboratively to solve complex, real-world clinical cases. Adaptive learning is facilitated through intelligent platforms that monitor students' progress in real time and deliver personalized content tailored to their needs. These systems are further enhanced by digital simulations with virtual patients, enabling experiential learning in a safe, controlled environment (Clark, 2009). In addition, Maastricht University has implemented virtual reality (VR) to enrich PBL scenarios, offering immersive learning experiences that foster deeper cognitive engagement (Maastricht University, 2024).

The university has also introduced AI-based intelligent tutoring systems that dynamically adapt content and feedback to the learner's pace and style. These innovations are supported by EDLAB-funded projects that focus on AI-enhanced assessment, personalized coaching, academic writing, and ethical use of educational technology (Maastricht University, 2025a). As part of the broader Strategic Programme 2022-2026, Maastricht is developing a virtual academic environment featuring adaptive recommendations and tailored learning activities (Maastricht University, 2022-2026). Gamification has been embedded into the instructional design not as mere motivation boosters, but as integral elements supporting continuous engagement. Tools such as digital badges, progress bars, and peer leaderboards promote consistent participation and encourage self-regulation, critical thinking, and collaboration (Dreier-Wolfgramm et al., 2018; Groen et al., 2019). The effectiveness of this comprehensive integration is assessed through a combination of pre/post-testing, retention metrics, and longitudinal performance data. Student feedback has been overwhelmingly positive, with satisfaction rates exceeding 85% in VR-supported sessions (Maastricht University, 2024).

DOI 10.36158/97912566920713

Reports indicate improved academic outcomes, especially among students with lower initial performance, reduced cognitive load, and better mastery of both theoretical and clinical skills (Sweller et al., 2011; de Jong et al., 2021). Furthermore, projects showcased during the UM Education Days 2025 demonstrated that the integration of generative AI tutors significantly enhances engagement, facilitates self-study, and provides timely feedback – while also highlighting challenges such as digital equity and the risk of cognitive overload if immersive tools are not carefully implemented (Maastricht University, 2025a). Although Maastricht's model is tailored to a PBL-centric environment, aspects of its TEL approach can be adapted to other educational settings through open-source platforms and pedagogical redesign. However, transferring such a model to lecture-based systems requires structural changes to ensure cognitive load remains balanced and students receive personalized support (Kirschner et al., 2006). This case study reinforces how the synergy between adaptive technologies, gamified learning, and active pedagogies can result in improved learning outcomes. Students report greater confidence in clinical problem-solving and a better ability to apply theoretical knowledge in practical contexts (Mayer, 2005; Papert, 1980).

6. Conclusion

The analysis of the literature and case studies – particularly the example of Maastricht University – confirms the transformative potential of combining adaptive learning, gamification, and Artificial Intelligence (AI) in contemporary education. Technologies such as adaptive platforms, Virtual and Augmented Reality (VR/AR), and intelligent tutoring systems are no longer peripheral supports but are becoming central pillars of effective instructional design. These tools provide real-time personalization, enable experiential learning, and significantly increase student motivation and engagement.

When integrated with active pedagogies like Problem-Based Learning (PBL), these technologies not only enhance motivation but also foster deeper cognitive engagement, knowledge retention, and the development of transversal skills such as critical thinking, collaboration, and cognitive flexibility. The Maastricht case demonstrates how a well-structured pedagogical framework – enriched by gamified elements and adaptive AI technologies – can boost academic outcomes, support learners at different levels, and reduce extraneous cognitive load without compromising educational quality (Maastricht University, 2024; 2025a). AI-based systems in particular represent a crucial step toward individualized, scalable learning. Through real-time monitoring and feedback, these systems dynamically adapt to each student's needs, offering targeted challenges and support. However, this evolution also introduces new challenges, including digital accessibility, ethical concerns, and the risk of over-reliance on automation, which may hinder the development of independent learning strategies and flexible cognition. Ultimately, the future of education lies not in technology alone, but in its thoughtful and pedagogically grounded integration. The most successful educational innovations are those that prioritize learner engagement, personalization, and meaningful learning, rather than simply adopting new tools. Ongoing research should continue to explore the long-term impact of these innovations, their adaptability across diverse learning environments, and the conditions for equitable and sustainable implementation.

DOI 10.36158/97912566920713

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The authors have no relevant financial or non-financial interests to disclose. We have no conflicts of interest to declare that are relevant to the content of this article. We certify that we have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. We have no financial or proprietary interests in any material discussed in this article.

DOI 10.36158/97912566920713