Educational Equity in Cognitive Cultivation: Gamified Elements in AI-Based Learning and Students' Cognitive Construction

Zihan Zhu *

Moray House School of Education and Sport, The University of Edinburgh, Nanjing, Jiangsu, China

* Corresponding Author Email: vrverae.vera@gmail.com

Abstract. The issue of educational equity has now received widespread attention. Although AI-based educational gamification platforms can provide personalised learning experiences, the differentiated mechanisms by which they influence different learners' cognitive and metacognitive development have not been fully revealed, which is of great significance for the realisation of educational equity. Through a literature review and theoretical integration, this paper systematically analyses the differences in cognitive engagement triggered by gamification elements and the multilayer mechanisms behind them. The analysis shows that identical gamification designs can produce markedly different behavioural responses and cognitive outcomes due to the complex interaction among platform mechanisms, contextual conditions, and individual learner differences. This paper proposes improvements to promote educational equity in three key dimensions. For inclusive design, emphasis should be placed on motivational incentives, cultural context, accessibility, and continuous improvement. In metacognitive scaffolding, platforms should introduce phased guidance and differentiated strategies, strengthen positive reinforcement for metacognitive behaviours, and empower teachers to provide targeted support. Regarding algorithmic transparency, educational platforms should establish clear, auditable, and accountable mechanisms, and increase transparency in disaggregated data.

Keywords: Educational equity; Gamification; AIbased learning platforms; Cognitive construction; Metacognition.

1. Introduction

In recent years, educational equity has emerged as a pressing global concern, with research continuing to reveal persistent disparities in educational opportunities, resources, and outcomes across diverse socio-economic and cultural contexts [1]. As digital technologies have become integral to contemporary education, AI-based learning platforms have garnered increasing attention for their ability to deliver personalized and adaptive educational experiences tailored to individual learners' needs [2]. Central to many of these platforms is gamification--the application of game-design elements in non-game contexts--to foster student engagement, motivation, and active cognitive construction [3].

Although the use of AI-based educational gamification platforms is becoming increasingly widespread, the specific pathways through which they affect different learners' cognitive and metacognitive development have not yet been systematically revealed, and these mechanisms are closely related to the realization of educational equity. Existing practice shows that even when the same gamification design is adopted, different students still display markedly different behavioural patterns and cognitive outcomes. This phenomenon suggests that gamification should not be understood solely at the technical level but examined from the perspective of the interaction among platform mechanisms, contextual constraints, and individual learner differences, in order to consider how it enhances or inhibits students' metacognitive ability and its deeper implications for educational equity.

Through a literature review and theoretical synthesis, this paper systematically analyses the differences in cognitive engagement triggered by gamification elements and the multi-layer mechanisms behind them, and on this basis explores the pathways by which feedback and visualization tools support metacognition and self-regulation. Furthermore, from the three dimensions of inclusive design, metacognitive scaffolds, and algorithmic transparency, the paper distils equity-oriented implementation principles and actionable improvement suggestions, providing theoretical grounding and practical references for building gamified learning systems that better accommodate individual differences and promote educational equity.

2. Differentiated Phenomena at the Level of Cognitive Elements

Reviews of the educational gamification literature indicate that even identical intervention designs often elicit markedly different behavioral patterns and cognitive outcomes across learners [3]. This section focuses on presenting these differentiated manifestations, analyzed from two angles: the functional differences of gamification elements and learners' behavioral responses.

2.1. Divergent Behavioural Patterns Triggered by Gamification Elements

Research shows that embedding gamification mechanisms into learning tasks tends to elicit systematically different user behavior trajectories, which in turn affect students' levels of participation and their equitable experience [4].

After introducing points, badges, and leaderboards (PBL) system, some students display stronger task engagement--for example, checking rankings more frequently and proactively completing more tasks to earn points [5]. Yet a considerable proportion of students--especially after rankings are published--show a decline in participation frequency, deliberately avoid competitive tasks, and repeatedly complete low-difficulty items. Motivation research suggests that over-reliance on relative ranking may undermine students' intrinsic interest, thereby reducing their willingness to attempt high-challenge tasks [6]. In contrast, when the feedback mechanism emphasizes personal progress and capability growth (e.g., "You improved by 10% compared with last time"), lower-achieving students are more likely to show a stable participation rhythm, higher rates of retrying incorrect items, and greater willingness to use supportive practice modules. This aligns with principles of effective feedback that focus on process and growth and can be explained by the support of intrinsic motivation through satisfying learners' need for competence [7,8].

Embedding narrative contexts likewise leads to pronounced behavioral divergence. When narrative content is highly aligned with learning objectives, it can effectively support novice understanding and reduce cognitive load. However, if the narrative is misaligned with the knowledge structure or has weak cultural relevance, it may introduce extraneous information and increase cognitive load [9]. This is especially the case for students whose cultural backgrounds differ from the narrative themes, as they must navigate an unfamiliar cultural discourse [10]. This often results in increased cognitive load, manifesting as extended periods lingering in dialogue segments, frequent help-seeking, and trial-and-error responding [9]. These behaviors indicate that narrative does not always lower cognitive barriers and, under certain conditions, may even constitute a new obstacle.

2.2. Typical Behavioural Pattern Classifications Across Learner Groups

Through clustering and sequence analysis of platform logs -- established methods for modelling learner behaviors [11]. This paper finds that different student groups exhibit stable and identifiable behavioral differences under the same instructional intervention. These behavioral clusters are often significantly associated with variations in their academic foundations, participation habits, and resource conditions.

First, students with different levels of prior knowledge behave quite differently in contextualized tasks. Learners with weaker foundations rely more heavily on contextual prompts (such as story cues and examples), with generally higher click frequencies and longer dwell times. However, learners with stronger foundations tend to skip narrative segments and proceed directly to core problems. This phenomenon is consistent with the "expertise reversal effect": contextual supports benefit novices but may interfere with more advanced learners [12].

Second, after introducing social-comparison elements such as leaderboards and group competitions, student behaviours diverge by ranking position. Students in favourable ranking positions are typically more active and more willing to select higher-difficulty tasks, showing clear goal orientation. While students in unfavourable ranking positions are more likely to exhibit declines in participation after ranking updates, practise low-difficulty content more frequently, and display hesitation and avoidance when facing challenging tasks. These behavioural patterns accord with the motivation-behaviour relationships described in self-efficacy and self-regulated learning theories [13,14].

Third, learners differ markedly in how deeply they use learning tools and feedback. Some systematically employ various tools--regularly checking progress panels, using self-assessment modules for preview and review, carefully reading explanations, and undertaking targeted practice thereafter. However, others, even when prompted about errors, rarely reattempt items, have low completion rates for lengthy explanatory texts, and seldom use planning functions. These behavioural characteristics reflect group differences in self-regulated learning and can be effectively captured by platform behavioural data [14].

Finally, access patterns and resource conditions are also closely associated with learner behaviour. Some students maintain regular access, have sufficient session length per visit, and enjoy stable connections. However, others exhibit more fragmented access (e.g., longer sessions only on weekends), higher early-exit rates in tasks involving streaming media or complex interactions, and shorter dwell time on text-heavy tasks. These differences reflect the impact of resource accessibility and support conditions on learning opportunities [15,16].

In sum, the diverse behavioural patterns observed in educational gamification indicate a complex and dynamic interaction between uniform instructional interventions and students' responses. Research shows that different game elements often elicit distinctly different participation behaviours and learning trajectories. These phenomena suggest that advancing educational equity cannot rely solely on standardized solutions. Instead, greater emphasis should be placed on the feedback role of behavioural data, moving towards adaptive, personalized instructional design. By identifying the typical behavioural characteristics of different groups and providing matching learning pathways and resource support, equity in the educational process can be promoted more genuinely.

3. Causes and Mechanisms: Platform Design, Contextual Constraints and Learner Differences

This section builds on the discussion of behavioural differences in the previous section to further analyze the mechanisms behind their formation. Learning outcomes are not determined by a single design but arise from the joint action of the platform system, contextual conditions and individual learners. The platform, through mechanisms such as feedback, scaffolding and adaptivity, first sets up the basic framework for learning interactions [2,9]. The macro-level context, through resources, culture and institutional factors, moderates the actual effects and usable boundaries of platform design. Ultimately, learners' cognitive and metacognitive abilities determine how they receive, interpret and translate these external supports [14]. Therefore, promoting educational equity cannot rely on standardized solutions. It requires system-wide coordination across the platform, context and learner levels [17].

3.1. The Platform's Mediating and Adaptive Mechanisms

Platform guidance mechanisms constitute the basic framework of learning interactions. By modulating cognitive load, reshaping motivational framing and providing metacognitive support, they build a more equitable pathway of progress across different learners [2]. First, at the motivational level, guidance mechanisms--such as emphasizing self-referenced progress feedback (e.g. "10% improvement since last time") or embedding error classification and strategy prompts--can influence how learners interpret incentive signals and thereby alter their behavioural responses [6,7]. Second, at the cognitive level, adaptive task sequencing and dynamic scaffolding should adjust difficulty and prompt intensity based on real-time performance. This mechanism both prevents beginners from giving up due to cognitive overload and avoids loss of engagement among high-level learners when tasks are too easy [12]. Finally, explainability at the institutional and data levels--such as opening the basis of algorithmic recommendations, providing learning-path traceability and visualisations of group comparisons--helps to reveal potential design biases and provides a foundation for understanding the subsequent influence of contextual and individual factors [2].

3.2. The Moderating Role and Structural Constraints of Context

Once the platform provides the basic interaction framework, contextual factors significantly moderate the actual effects and usable boundaries of these design mechanisms. First, resources and infrastructure directly affect whether students can smoothly participate in platform activities and the quality of the data. For example, unstable networks or low-performing devices can lead to frequent interruptions, undermining the integrity of platform design [18,19]. Second, linguistic and cultural adaptation is crucial. When the platform's narrative aligns with students' cultural backgrounds, these contextual elements can serve as cognitive "scaffolds". Conversely, cultural distance or unfamiliar terminology adds extraneous cognitive load, making it difficult for the design to achieve its intended effects [9,10]. Finally, classroom organization and institutional arrangements also alter the educational meaning of platform elements. If teachers incorporate collaboration and reflection into the course, platform feedback may become part of a collective cognitive process [20]. By contrast, in environments that emphasize individual competition, points and leaderboards are more likely to trigger social comparison and lead some individuals to avoid challenges [8]. In sum, context functions as an important moderating mechanism: it both limits the practical usability of platform functions and affects the fidelity with which behavioral data represents ability and motivation [20].

3.3. Learners' Cognitive and Metacognitive Differences

After the platform provides the basic framework and contextual factors exert moderation, the ultimate learning outcomes depend on learners' individual cognitive and metacognitive abilities. First, students' prior knowledge influences the effects of gamified platform design through cognitive load. The "expertise reversal effect" indicates detailed explanations and contextualized design that benefit novices may instead become interference for high-level learners [12]. Second, motivation and self-efficacy shape how students understand the motivational signals sent by the platform. Students with high self-efficacy are more likely to viewpoints and rankings as yardsticks of capability growth. However, those with lower self-efficacy are more prone to feeling threatened by social comparison, which manifests as fewer instances of participation [6,13]. Finally, metacognitive ability determines whether learners can truly improve based on platform feedback. Students skilled in metacognitive strategies, as characterized by self-regulated learners, will use feedback systematically. In contrast, those with weaker metacognitive ability, even when aware of errors, often lack the subsequent adjustment strategies necessary for feedback to be effective, a key distinction in the model of feedback efficacy [7,14]. Individual differences are therefore a key internal factor affecting the ultimate translation into learning gains.

In summary, achieving equity in educational gamification relies on "three-layer interaction": the platform builds the basic framework, context moderates design effects, and learners determine the final translation. Only by systematically identifying and jointly optimizing this three-layer structure can gaps be narrowed, learning opportunities expanded, and outcome fairness enhanced at the source [1, 2].

4. Equity-Oriented Design and Implementation Recommendations

Drawing on the preceding analysis of the interaction mechanism among the "platform-context-learner" triad, this section proposes practical strategies. These mainly include avoiding unnecessary social comparison and cultural distance in design, organizing tasks and feedback around metacognition during learning, and using explainable and measurable mechanisms to drive continuous optimization.

4.1. Inclusive Gamification Design

To achieve a genuinely inclusive gamified learning environment, design should be advanced systematically across four dimensions--motivational incentives, cultural context, accessible entry, and ongoing improvement--to support the effective participation of students with different backgrounds, ability levels, and motivational states.

First, in terms of incentive mechanisms, greater emphasis should be placed on students' individual progress rather than competition with others. Compared with highlighting public rankings, the feedback mechanism should foreground the trajectory of personal growth, which helps maintain participation among students with weaker motivation and reduces the tendency to choose low-difficulty tasks to avoid failure [5,6]. For example, leaderboards may omit specific ranks and instead present the ability band in which a student is located, while allowing learners to decide whether to make it public. The points system should encourage challenging attempts and effective retries so that students realize that "attempting and revising" has value in itself [8]. In addition, drawing on the principles of cooperative learning, tasks can be designed with positive interdependence and complementary roles to ensure students with different backgrounds and abilities make unique contributions, thereby building trust and a sense of belonging [16]. Such adjustments do not weaken motivation. Rather, they shift the focus from external comparison to awareness and control of one's competence development [4].

Second, the game setting and narrative should embody cultural inclusivity and diversity. In background settings, character design, and visual elements, a single cultural perspective should be avoided, and diverse cultural content should be actively incorporated to ensure that students from different cultural backgrounds can develop identification and immersion. A typical case is Minecraft: Peace Builders, developed in collaboration with the Nobel Peace Center. This game introduces the deeds and practices of Nobel Peace Prize laureates and also supports localisation, allowing students to connect the history of peacebuilding with their own community contexts. In this environment, learners can express understanding through building, role-playing, or task feedback. This flexibility aligns with the Universal Design for Learning (UDL) principle of multiple means of expression [1]. The game context should become a bridge for cross-cultural understanding and inclusion, rather than creating new cognitive or cultural barriers.

At the same time, attention must be paid to usage barriers arising from differences in physical conditions. Interface design should strictly follow accessibility principles, ensuring screen-reader compatibility, sufficient colour contrast, and adjustable font size. Interactions should also support multiple modes such as keyboard navigation and voice control. Then, content presentation should provide alternative formats such as captions and audio description [2].

Finally, inclusive design should be regarded as a dynamic process of continuous improvement rather than a one-off task. It is necessary to establish regular feedback mechanisms, periodically collect opinions from users with different cultural backgrounds and physical conditions, and incorporate the depth of diversity adaptation into product updates and optimization processes [1]. In addition, diverse design teams should be formed so that users with different cultural perspectives and physical and mental characteristics can participate in key decisions, thereby reducing unconscious bias at the source and truly embedding inclusion into the product's DNA [2].

4.2. Metacognition-Centred Learning Scaffolds

Platform support should go beyond basic functions such as delivering items and scoring, and integrate planning, monitoring, and reflection deeply into the entire learning process to enhance students' learning ability systematically. Specifically, the support system can be constructed along four levels.

First, establish a phased guidance mechanism. Before tasks begin, the platform should help students set clear goals, choose appropriate strategies, and plan time. During tasks, it should set checkpoints to guide students to assess confidence levels, identify error types, and provide strategy prompts, when necessary, thereby cultivating self-regulation. After tasks, it ought to use error notebooks and spaced review to strengthen memory, and design transfer tasks to test mastery, turning feedback into continuous progress [7].

Second, implement differentiated support strategies that respond to the expertise reversal effect. This phenomenon, known as the expertise reversal effect, is a key principle of cognitive load theory [9, 12]. It indicates that instructional support effective for novices may become redundant or even interfere as expertise grows. Therefore, the system should adapt dynamically to learner levels: provide adequate scaffolding for beginners and options to skip redundant explanations for advanced learners, keeping cognitive challenge appropriate.

Third, strengthen positive feedback for metacognitive behaviours. For students with low confidence, incorporate key self-regulatory learning strategies--such as planning, challenging attempts, effective retries, and scheduled review--into the reward mechanism [14]. By recognizing these "learning to learn" behaviours with points or badges, the platform can help create mastery experiences that enhance self-efficacy [13].

Fourth, empower teachers to deliver targeted support. Learning analytics dashboards, as extensively reviewed in educational technology research, can help teachers identify students who lack planning, repeat errors without correction, or exit learning segments early. This enables timely intervention and personalized assistance and improves tutoring efficiency and embodies data-informed education.

4.3. Transparency, Accountability, and Equity Metrics

Advancing algorithmic transparency and fair governance in educational platforms is key to ensuring that technology truly serves education.

First, many automated systems are described as "black boxes" because their internal logic is opaque and may hide subtle biases. Thus clear, auditable, and accountable mechanisms are needed [2]. For example, when the system recommends learning tasks, it should explain the reason in an understandable way--such as "this content is recommended to help you consolidate weak knowledge points"--while providing alternative learning paths. Furthermore, to ensure ethical and transparent operation, the system must clearly inform users of the purposes of data use and allow authorisation to be revocable at any time. Finally, to realise effective human-machine co-decision-making, teachers should have one-click control over key settings (such as task time limits, leaderboard display, and scoring weights), with all operations being traceable [2].

Second, to evaluate educational equity and effectiveness, a three-tier framework of opportunity-process-outcome can be established, with strengthened transparency in disclosing grouped data. At the opportunity level, focus on resource accessibility, including student activity, continuity of learning, and completion under poor network conditions, to identify potential participation barriers [1]. At the process level, attend to behaviours--informed by gameful design research--such as attempts at high-difficulty tasks, effective retries, deep use of hints, and changes in participation after leaderboard updates [4]. These behaviours can reveal underlying motivational and strategic differences across groups, as explained by theories of human motivation [6]. Outcome evaluation should look beyond overall progress to analyze improvement among students with different starting points and changes in intergroup gaps. Furthermore, it should assess metacognitive components, such as the calibration between confidence and accuracy, as well as long-term retention and transfer [14]. This multifaceted approach, aligned with principles of effective feedback, is essential to distinguish real learning gaps and provide appropriate support [7].

In sum, educational equity should not be treated as a post hoc add-on but as a foundational principle embedded in the platform's underlying design, interaction logic, and evaluation system. By attenuating unnecessary lateral comparison and cultural bias, providing learning feedback that supports autonomous adjustment, and establishing transparent and measurable mechanisms for continuous improvement, platforms can address resource and cultural differences in real classrooms and enable every student to obtain growth support that truly suits them.

5. Conclusion

Educational gamification shows a pronounced differentiation effect in practice: identical design elements can trigger sharply different behavioral responses and cognitive outcomes in different learners. This study analyses this phenomenon from the functional differences of gamification elements and the differences in learners' behavioral patterns and points out that it involves a complex interaction across three levels--platform mechanisms, contextual conditions, and individual learners. The platform provides the basic framework for learning interactions. Contextual factors moderate the actual effectiveness and usable boundaries of that framework, and learners' cognitive and metacognitive abilities determine how external supports are transformed into genuine learning outcomes. This "platform-context-learner" threefold interaction mechanism implies that promoting educational equity cannot rely solely on standardized solutions but requires systemic, coordinated optimization.

On the basis of this mechanism, this paper proposes advancing educational gamification practice around three aspects: inclusive design, metacognitive scaffolds, and transparent governance. Specifically, this includes avoiding excessive social comparison in incentive design and emphasizing individual progress and diverse contributions, embodying cultural inclusivity and accessibility in narrative and interface design, embedding planning, monitoring, and reflection into learning support to strengthen metacognitive ability, and, in platform governance, enhancing algorithmic transparency and the explainability of evaluation mechanisms, while establishing a fairness monitoring system based on "opportunity-process-outcome".

The realization of educational equity requires fundamentally embedding differentiated needs into designing logic and support systems. The future development of educational gamification should attach greater importance to the feedback role of behavioral data and, through adaptive mechanisms, provide different students with growth pathways that genuinely fit their needs. Only in this way can technology play its enabling role in diverse educational contexts and promote educational practices that are both more individualized and more inclusive.

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