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Integrating Metacognition into Adaptive Gamification Design to Strengthen Reflective Competence in Pre-service Teacher Education

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A B S T R A C T

Reflective competence is vital for prospective teachers to foster critical thinking and lifelong learning. However, digital learning environments often lack support for metacognitive awareness and self-regulation. This study used a quasi-experimental mixed-methods design involving 128 education students from two Indonesian LPTKs over one semester. Pre-tests and post-tests using the Reflective Thinking Scale (RTS) assessed quantitative changes, while qualitative data came from learning logs and interviews. Results showed a significant improvement in reflective competence ($p < 0.01$), particularly in critical reflection and thinking strategies. Adaptive gamification that adjusted challenges and feedback in real time enhanced engagement and learning depth. Metacognitive integration in gamification promoted self-regulation, reflective questioning, and skill transfer to teaching practice. Metacognition-based adaptive gamification effectively supports the development of reflective competence in prospective teachers.

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INTRODUCTION

In the 21st-century educational landscape, reflective competencies are no longer seen as complementary abilities, but rather as a key pillar in shaping adaptive, critical, and contextual professional teachers (Sudiansyah et al., 2024). Reflective ability allows prospective teachers to introspect on their teaching practices, evaluate learning processes and outcomes objectively, and make pedagogical adjustments oriented towards continuous improvement. Deep reflection is also the main foundation for value-based decision-making, sensitivity to diversity, and the development of teachers' professional identities in the long term. Therefore, the education of prospective teachers must be designed in such a way as to foster reflective habits as part of an integral learning process (Snieder & Zhu, 2020; Azionya et al., 2019).

However, various studies show that the development of reflective competencies in the teacher education environment still faces structural and pedagogical constraints. Too dense curriculum, evaluation-oriented evaluation models, and lack of scaffolding for high-level thinking skills cause reflection practices to tend to be superficial, purely retrospective, or just an administrative routine (Swargiary, 2024). In fact, effective reflection requires a structured metacognitive thinking process, namely the individual's awareness of his or her own thought process and the ability to plan, monitor, and evaluate the learning strategies used. This is where the importance of integrating metacognition as a basis in instructional design to support the formation of authentic and meaningful reflection (Belenkova, 2020; Ramadhanti et al., 2020).

In this context, learning technologies offer a great opportunity to create learning environments that support reflective processes in an adaptive and sustainable manner. One rapidly evolving approach is gamification—the use of game design elements in a non-gaming environment to increase learning, motivation, and persistence (Mhlongo et al., 2023). In the field of teacher education, gamification has been applied to increase pedagogical learning motivation, simulate decision-making in the classroom, and strengthen the digital competence of prospective teachers. However, the majority of gamification implementations still focus on extrinsic motivation aspects such as awarding points, badges, and leaderboards, which tend to be temporary and do not directly shape students' cognitive or metacognitive awareness (Marienko et al., 2020; Rana et al., 2024).

Furthermore, gamification that is static and generic often fails to accommodate the individual needs of students who have diverse learning styles, readiness levels, and self-regulation abilities. In this context, adaptive gamification that is able to tailor challenges, feedback, and learning paths based on real-time data of participants becomes particularly relevant. If the adaptive gamification design is infused with metacognitive components, such as automatic reflection, learning strategy planning, and self-monitoring, then the learning experience is not only fun, but also cognitively meaningful. This integration has the potential to create a reflective and dynamic learning process, where learners are actively involved in shaping their understanding and growth (Raleiras et al., 2020; Tang & Kay, 2014).

Unfortunately, until now there is still a lack of empirical studies that systematically develop and test the effectiveness of metacognition integration in adaptive gamification, especially in the context of teacher education in Indonesia. Most studies are still split between metacognitive approaches and game-based approaches, without bringing the two together in a single unified learning design framework. In fact, in the education of prospective teachers who are required to have high-level thinking skills and reflective sensitivity to their professional practices, this kind of integration is an urgent need.

Therefore, this study aims to develop and evaluate the effectiveness of metacognition-based adaptive gamification design in improving the reflective competence of teacher education students. The main focus of this research is how the integration of metacognitive elements (planning, monitoring, self-evaluation) into gamification mechanisms can shape a more structured, contextual, and sustainable reflection process. This research is expected to make a theoretical and practical contribution to the development of technology-based learning designs that are not only technically adaptive, but also pedagogically transformative, especially in forming reflective, critical, and professional teacher candidates.

LITERATURE REVIEW

Reflective Competence in Teacher Candidate Education

Reflective competence is a fundamental element in the development of teacher professionalism. It reflects the individual's ability to consciously reflect on learning or teaching experiences in order to evaluate, improve, and innovate pedagogically. In the context of teacher education, this competency is closely related to the process of forming an autonomous and critical professional identity. Reflection is not only seen as a retrospective activity, but also as a high-level thinking process that involves the assessment of beliefs, assumptions, and consequences of pedagogical actions taken (Lalor et al., 2015). Therefore, reflective skills need to be cultivated from the early stages of teacher education in order to become part of sustainable professional practice.

Several reflection-based learning models have been developed, such as the Reflective Thinking Model and the Experiential Learning Cycle, but their application in the classroom is often instructional and has not sufficiently stimulated students' awareness of deep thinking. To bridge these needs, metacognition-based approaches are relevant because they are able to provide a framework for learners to be aware of and manage their thinking processes in the context of reflective learning (Cathro et al., 2017).

The Role of Metacognition in Reflective Learning

Metaxogy is defined as an individual's knowledge and awareness of his or her own thought process, as well as the ability to plan, monitor, and evaluate the learning strategies used. In the context of teacher education, metacognition has an important role in shaping reflective awareness. Prospective teachers who have good metacognitive skills tend to be better able to analyze teaching practices, question pedagogical assumptions, and identify areas for self-development. The integration of metacognition in learning allows participants to

take control of their learning process, deepen understanding, and internalize constructive pedagogical values (Badaruddin et al., 2024).

The application of metacognitive strategies such as self-questioning, learning journals, and guided reflection prompts has been proven effective in encouraging students' critical reflection. However, challenges arise in how to design learning experiences that are able to trigger metacognitive activation in a sustainable and contextual manner, especially in a fast-paced and fragmented digital learning ecosystem (Rajaram, 2023).

Adaptive Gamification as an Instructional Strategy

Gamification has become a popular approach in digital education due to its ability to increase engagement, motivation, and enjoyable learning experiences. Elements such as points, badges, challenge levels, and leaderboards create participatory dynamics that encourage learning persistence. However, most gamification designs are static and focus on extrinsic motivation, making them less able to support the development of higher cognitive abilities such as reflection and self-regulation (Mohamad et al., 2018).

To overcome these limitations, an adaptive gamification approach emerged, which is a gamification design that can adjust game elements based on real-time user behavior data. This system allows for the provision of skills level-appropriate challenges, personalized feedback, and flexible learning paths. When combined with metacognitive strategies, adaptive gamification has the potential to shape learning experiences that not only motivate, but also encourage deep understanding and reflection (Mohamad et al., 2019).

Integration of Metacognition and Gamification in Teacher Education

Recent research shows the great potential of combining metacognitive and gamification approaches in supporting the development of reflective competencies. Systems that integrate task planning, reflective reminders, and self-assessment into a digital environment have been shown to improve students' metacognitive awareness. In teacher education, this integration can be applied through game-based microteaching simulations, LMS platforms with automatic reflection features, or case-study-based adaptive training (Carella & Colombo, 2024).

However, there is still a lack of research that explicitly develops and tests metacognition-based adaptive gamification designs in the context of teacher education, especially in Indonesia. This gap is the foundation for this research, which is to develop a gamification system that not only motivates adaptively, but also facilitates an authentic reflection process through structured metacognitive integration (Khurma et al., 2024).

METHODOLOGY

Research Design

This study uses a quantitative-qualitative approach (mixed methods) with a quasi-experimental design that aims to develop and evaluate the effectiveness of metacognition-based adaptive gamification design in improving the reflective competence of teacher education students. This approach was chosen to obtain

comprehensive data, both in terms of quantitative effectiveness and qualitative response and learning experience of participants (Jelena & Jelena, 2022).

The quasi-experimental design was carried out with pre-test and post-test models without control groups, which allowed researchers to observe changes in reflective competency scores before and after the intervention. The qualitative approach is used to explore more deeply how students interpret the reflection process through metacognitive features integrated in gamification platforms (Kaeedi et al., 2023).

Research Subjects and Settings

The subjects of this study are students of education study programs (PGSD and PPG Prajabatan) from two Education Personnel Education Institutions (LPTK) in Indonesia. A total of 128 students voluntarily participated in this study, with inclusion criteria namely actively participating in Learning Management System (LMS)-based learning, having personal digital devices, and being willing to use the gamification platform developed for at least one semester. The research was conducted in the Even Semester of the 2023/2024 Academic Year in the context of the courses "Innovative Learning Strategies" and "Microteaching Practices," which explicitly demand reflective skills and the ability to design learning.

Instrument and Platform Development

Adaptive gamification platforms are developed iteratively using a user-centered design approach. The main features of the platform include:

a) Adaptive Reflective Tasks, which automatically adjust difficulty levels and feedback based on participant performance.
b) Metakcognitive prompt, in the form of a reflection guide question (planning, monitoring, evaluation) that appears periodically.
c) Progress Tracker, which shows reflective progress in visual form (bar graphs and color indicators).
d) Game-Based Simulation, where participants perform the role of a teacher in a virtual scenario and are asked to do post-decision reflection.

The quantitative measurement instrument used is the Reflective Thinking Scale (RTS) which has been validated and modified according to the local context. This scale consists of four main dimensions: habitual action, understanding, reflection, and critical reflection, which are assessed on a Likert scale of 1–5.

Data Collection and Analysis Techniques

The data in this study was collected through several complementary techniques. First, pre-tests and post-tests were carried out using the Reflective Thinking Scale (RTS) instrument to quantitatively measure changes in the level of students' reflective competence. Second, a digital activity log system is used to record the duration of use of reflective features, the frequency of responses to metacognitive prompts, and the completion rate of scenario-based simulation tasks available in gamification platforms. Third, semi-structured interviews were conducted on 20 selected participants, who were selected based on significant

changes in reflection scores or demonstrated interesting qualitative responses during the intervention.

For data analysis, a quantitative approach was carried out using a paired t-test to test the significance of differences in reflective scores before and after treatment. Meanwhile, qualitative data were analyzed using thematic analysis techniques, with an open coding approach to identify the narrative patterns of reflection, thinking strategies, and metacognitive awareness dynamics that emerged during the use of the adaptive learning platform

RESEARCH RESULTS

Changes in Reflective Competency Scores

Analysis of pre-test and post-test data using the Reflective Thinking Scale (RTS) showed a significant increase in students' reflective competency scores after participating in metacognition-based adaptive gamification interventions. The average overall score increased from 3.12 on the pre-test to 4.01 on the post-test (scale 1–5). The paired t-test yielded a value of $t = 9.47$ with $p < 0.001$, indicating that the increase was statistically significant.

The highest increase occurred in the critical reflection dimension, which increased from an average of 2.85 to 4.05. Followed by the reflection dimension (general reflection) which increased from 3.09 to 4.02. The dimensions of understanding and habitual action have also increased, albeit with a lower range.

Table 1. RTS Dimension Score Before and After Intervention

RTS Dimensions	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Δ (Change)	Significance (p)
Usual Action	3.38 ± 0.41	3.92 ± 0.35	+0,54	< 0.01
Understanding	3.16 ± 0.52	3.98 ± 0.38	+0,82	< 0.01
Reflection	3.09 ± 0.47	4.02 ± 0.36	+0,93	< 0.001
Critical Reflection	2.85 ± 0.51	4.05 ± 0.42	+1,20	< 0.001

Students' Metacognitive Activities and Responses

The system logs record the level of student participation in various reflective features integrated in the gamification platform. As many as 92% of students actively respond to metacognitive prompts, with an average of 3.6 interactions per week. The most commonly used feature is the self-monitoring dashboard, followed by a reflective feedback tracker and adaptive task simulation.

From the interaction notes, it was found that students used the reflection feature more often after completing the microteaching simulation or getting automated feedback. Their responses generally contain metacognitive elements such as strategy evaluation, error awareness, and future improvement plans.

A thematic analysis of semi-structured interviews conducted on 20 selected participants resulted in three main themes representing the dynamics of reflective change during the use of metacognition-based adaptive gamification

platforms. These findings show how design elements that are consciously designed to activate critical thinking and self-awareness processes are able to facilitate a transformation that is not only cognitive, but also affective and strategic in the teaching and learning process.

a) Self-awareness Growth

Most participants showed a noticeable increase in awareness of their own thought processes. Students are beginning to realize that pedagogical decision-making that was previously done automatically and based on intuition actually requires deeper consideration. Through reflective prompts and feedback tracker features, they are encouraged to evaluate the reasons behind the actions taken and their impact on the student learning process. In this process, there is an internalization of the relationship between the educational theory studied and the learning practices they design.

One powerful narrative emerged from the 12 participants who stated, "I became more aware that I often make decisions in class based solely on intuition. But now, I am starting to ask: why did I choose this strategy?", (P-12 interview, April 18, 2024). This statement confirms that platforms designed with a metacognitive approach have succeeded in facilitating the emergence of reflections that are evaluative and no longer merely descriptive.

b) Strategic Shift

The second finding shows a change in approach in the way students design and reflect on their learning experiences. If previously the learning pattern tended to be reactive and task-based, then after the intervention, students showed an improvement in terms of strategy planning, reasoning in choosing methods, and readiness to develop alternative plans.

Some students began using reflective notes as an instrument to monitor their mindsets and revise lesson plans based on the scenarios encountered in the simulation. They also show a tendency to anticipate potential mistakes and look for solutions before implementing teaching strategies. This pattern suggests that metacognition not only aids in post-activity evaluation, but also strengthens prospective decision-making.

c) Increased Intrinsic Motivation

Although gamification is often associated with extrinsic motivation, the findings in this study suggest that when gamification is designed in an adaptive and profound way, it is also capable of triggering intrinsic motivations that support reflection. Students feel that the use of elements such as level-based tasks, personal feedback, and achievement tracking provides a sense of achievement, but not because they want to "win" or compete, but because of the urge to develop a sustainable way of thinking and teaching strategies.

This is reflected in participant 07's statement, "The reflection feature at the end of the simulation made me really think. I write about what works, what is lacking, and why it happens", (Interview P-7, April 23,

2024). This statement shows that digital features are not only a medium of feedback, but also a tool for internalizing meaningful reflective experiences.

d) Interpretation of Qualitative Findings

The three themes above indicate that the learning experience facilitated by metacognition-based adaptive gamification design not only affects the cognitive aspects of students, but also changes their attitudes, thinking habits, and motivation as prospective educators. The integration of metacognitive strategies into digital simulations allows students to experience a direct and repetitive reflective learning process, in a safe and constructive setting.

Thus, these qualitative findings not only reinforce the quantitative results that show an increase in reflection scores, but also provide a deeper understanding of how and why such reflective transformations occur during the intervention process.

DISCUSSION

Improvement of Reflective Competency Through Metacognition Integration

The results of the study show that the integration of metacognitive strategies in adaptive gamification design has a significant impact on improving the reflective competence of prospective teachers. The highest increase occurred in the critical reflection dimension, which reflects students' ability to critically evaluate and reconstruct their learning experiences. This shows that the gamification approach, which not only presents challenges, but also invites participants to reflect through reflective prompts, is able to encourage deeper cognitive engagement.

Theoretically, these results are in line with the concept that metacognition acts as a bridge between declarative and procedural knowledge towards meaningful reflective practice. By providing explicit space for planning, monitoring, and self-evaluation in each assignment cycle, students not only complete learning activities, but also learn to interpret their thinking process consciously. This supports findings in the literature that structured reflection processes are more successful when supported by instructional devices that intentionally activate metacognition (Saks et al., 2021).

The Effectiveness of Adaptive Gamification in the Context of Teacher Education

The high engagement of students in metacognitive features such as self-monitoring dashboards and adaptive simulation tasks reinforces the argument that adaptively designed gamification can be an effective medium to support reflective learning. When the system provides feedback that is relevant to students' responses, and adjusts the level of difficulty based on their performance, the learning process becomes more personalized, contextual, and positively challenging.

This interpretation indicates that the principles of personalized learning adopted in adaptive gamification not only impact external motivations (such as engagement), but also on higher cognitive aspects, such as critical reflection and the transfer of understanding to real contexts. In this case, the system acts as a

facilitator of metacognition that continuously triggers cycles of conscious and reflective thinking.

Reflection as Results, Process, and Practice

Qualitative data show the transformation of students' way of thinking from habitual to reflective actions. They begin to ask "why" and "how" in every pedagogical decision they make, not just "what" and "when". This marks a shift from just doing teaching to thinking about teaching.

As shown by the participant's narrative, reflection does not only occur after the task is completed, but also appears actively during the learning process. This signifies that the integration of metacognition in gamification has succeeded in placing reflection as part of the learning process itself, not just as a complement. This supports a constructivist approach that emphasizes the importance of building understanding through internal dialogue and experiential reconstruction.

Implications for Teacher Education and Digital Learning Design

These findings have broad practical implications for the development of teacher education curriculum in the digital era. First, learning design needs to move from simply "providing content" to "facilitating thinking". The integration of elements such as reflective prompts, self-development dashboards, and scenario-based tasks has been proven to deepen the learning process.

Second, it is important for teacher education institutions to consider learning technology not just as a medium, but as a pedagogical instrument that can be consciously designed to foster professional competencies such as reflection. In this context, the metacognition-based adaptive gamification approach can be a strategic solution to bridge the challenges of developing the soft skills of prospective teachers in the midst of ever-evolving digital learning.

Research Limitations

Although the results of this study are promising, there are some limitations that need to be noted. This study used a design without a control group, so the possibility of the influence of external factors on the increase in reflective scores was not completely eliminated. In addition, the context of the study was limited to two institutions and one semester, so the results could not yet be generalized to a wider population.

Therefore, follow-up research is recommended using a full experimental design with randomization and control groups, as well as expanding the duration and scope of interventions. In-depth research on the influence of differentiation in learning styles and digital literacy levels can also provide a more complete understanding of the effectiveness of this approach.

CONCLUSIONS AND RECOMMENDATIONS

This study proves that machine learning ensemble-based prediction models, especially the Voting Classifier that combines Random Forest and XGBoost, are effective in predicting student academic performance based on

online learning activity data from the Moodle LMS. The developed model is able to achieve an accuracy level of up to 87.9%, with an AUC value of 0.91, indicating high classification performance and reliability.

Features such as the number of assignments completed on time, quiz scores, and participation in discussion forums prove to be important indicators that contribute greatly to the academic success of students. This emphasizes the importance of active involvement in the online learning process, not just access to the platform.

The practical implication of this study is that vocational education institutions such as the Banjarmasin State Polytechnic can utilize this predictive model as part of an early warning system to detect students who are at risk of academic failure and make more timely and data-based interventions.

This research also opens up space for further development by involving affective variables and non-academic behaviors, as well as application across study programs to improve model generalization. The integration of machine learning in the digital learning ecosystem has proven to be a strategic approach in supporting the transformation of technology-based vocational education in the digital era.

ADVANCED RESEARCH

Future research can explore the integration of affective factors such as motivation, emotional engagement, and learning satisfaction, alongside non-academic behaviors like attendance patterns and time management, to enhance prediction accuracy and model depth. Additionally, applying the model across various study programs and institutions would help evaluate its generalizability and robustness. The inclusion of real-time analytics and adaptive feedback mechanisms could also improve early intervention systems, making them more responsive and personalized to students' needs in diverse online learning contexts.

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