

INTISARI

Penerapan gamifikasi dalam pelatihan perakitan virtual berpotensi menurunkan beban kognitif dan meningkatkan keterlibatan operator. Namun, dinamika interaksi antara elemen gamifikasi dan kompleksitas tugas perakitan terhadap aspek kognitif dan keterlibatan berdasarkan pengukuran multimetode (subjektif, objektif, dan neurofisiologis) masih terbatas. Penelitian bertujuan menginvestigasi pengaruh elemen gamifikasi (poin dan lencana), kompleksitas tugas (sederhana:5 komponen; kompleks:40 komponen *engine*), dan perbedaan individu terhadap beban kognitif, keterlibatan, dan kinerja. Teori yang mendasari penelitian ini adalah dan *Cognitive Load Theory* (CLT), *Signal Detection Theory* (SDT), *Engagement Theory*, serta model *Skills-Rules-Knowledge* (SRK).

Penelitian telah lolos telaah etik dan terdiri dari dua tahapan. Tahap pra-eksperimen memprofilkan 130 responden menggunakan instrumen *Hexad User Type*, *Index of Learning Style* (ILS), dan *International Personality Item Pool-Big Five Factor Marker* (PIP-BFM) yang telah diuji reliabilitas dan validitasnya. Eksperimen utama menggunakan desain *within-subject* terhadap 11 partisipan laki-laki (divalidasi melalui analisis a priori *G*Power*). Partisipan menyelesaikan 16 blok tugas perakitan, 8 sederhana dan 8 kompleks dengan simulator *ARCarEngine*. Pengukuran meliputi metrik kinerja (kecepatan dan skor), evaluasi subjektif (RSME, *Two-Item Scales*, dan *Affective Slider*), objektif (waktu reaksi dan kesalahan), serta neurofisiologis menggunakan EEG OpenBCI ganglion empat kanal (menganalisis *Cognitive Load Index* (CLI), *Engagement Index* (EI) dan *Frontal Alpha Asymmetry* (FAA)).

Hasil penelitian mengungkap bahwa efek gamifikasi bergantung pada jenis elemen gamifikasi, kompleksitas tugas perakitan, repetisi dan perbedaan individu. Pada tugas sederhana, waktu tercepat dicapai tanpa gamifikasi. Sebaliknya, pada tugas kompleks, elemen lencana efektif meningkatkan kecepatan karena berfungsi sebagai penanda tahapan tanpa menambah beban kognitif, sementara kombinasi poin dan lencana meminimalkan kesalahan. Dinamika kompromi kecepatan-akurasi teridentifikasi: peningkatan keterlibatan kognitif dan emosional justru berkorelasi dengan perlambatan waktu perakitan untuk menjaga presisi deteksi sinyal. Lebih lanjut, repetisi tugas sederhana memicu anomali berupa lonjakan kesalahan di akhir eksperimen. Faktor perbedaan individu (kepribadian, gaya belajar dan tipe pengguna gamifikasi) teridentifikasi memengaruhi variabilitas kinerja. Secara neurofisiologis, elemen poin memitigasi digital *overload* dan mempercepat *learning curve* melalui peningkatan efisiensi neural melalui penurunan daya gelombang teta, alfa, dan beta di area *parietal* Pz, yang mempercepat transisi perilaku berbasis pengetahuan menuju perilaku berbasis keterampilan yang otomatis. Aktivitas alfa sentral Cz mengindikasikan bahwa kondisi istirahat korteks secara langsung memperlambat kinerja. Analisis FAA menunjukkan bahwa gamifikasi berbasis poin berfungsi sebagai stabilisator emosi negatif pada tugas kompleks (*germane load*) yang memfasilitasi konstruksi skema kognitif, sementara lencana pada tugas kompleks berisiko menjadi *extraneous load* jika tidak diselaraskan. Dapat disimpulkan bahwa penyeragaman desain pelatihan gamifikasi virtual tidak optimal. Penelitian ini merekomendasikan sistem gamifikasi adaptif yang memprioritaskan lencana untuk efisiensi kecepatan pada tugas kompleks dan mengombinasikan elemen untuk memaksimalkan akurasi.

Kata Kunci: Elemen Gamifikasi, Perbedaan Individu, EEG, OpenBCI, Ganglion.

ABSTRACT

The application of gamification in virtual assembly training can reduce cognitive load and enhance operator engagement. However, understanding of the interaction dynamics between gamification elements and assembly task complexity on cognitive and emotional aspects based on multi-method measurements—namely subjective, objective, and neurophysiological—remains limited. The purpose of this study is to investigate the effects of gamification elements, task complexity, and individual differences on cognitive load, emotional responses, and performance in a virtual assembly task. The investigated gamification elements are points and badges. Task complexity consists of a simple task (assembling 5 components) and a complex task (assembling a 40-component engine). The theoretical frameworks underlying this research are the Skills-Rules-Knowledge (SRK) model and Cognitive Load Theory (CLT).

The research consisted of two phases and has been exempted from ethical review (Exemption Letter No. 01.064/KEP-SOSHUM/X/2025). The pre-experimental phase profiled 130 respondents using the validated and reliable User Types Hexad Scale, Index of Learning Styles (ILS), and International Personality Item Pool-Big Five Factor Markers (IPIP-BFM) instruments. The within-subject neuroergonomic experimental phase involving 11 male participants was conducted in a laboratory. The sample size was validated through an a priori G*Power analysis. Participants completed 16 assembly task blocks—8 simple and 8 complex—using the ARCarEngine simulator. Measurements included performance metrics, subjective and objective evaluations, and physiological electroencephalogram (EEG) recordings using a four-channel OpenBCI Ganglion. The measured performance metrics were assembly speed and assembly score. Subjective evaluations were measured using the Rating Scale Mental Effort (RSME), Two-Item Scales, and Affective Slider. Objective evaluations measured average reaction time and response errors. Physiological evaluations were measured using the Cognitive Load Index (CLI), Engagement Index (EI), and Frontal Alpha Asymmetry (FAA).

The results reveal that the effects of gamification depend on the gamification elements, assembly complexity, task repetition, and individual differences. In simple tasks, the fastest completion time was achieved without gamification. Conversely, in complex tasks, the badge element effectively increased speed by serving as a procedural milestone without adding cognitive load. A combination of points and badges was necessary to minimize errors. High levels of cognitive and emotional engagement correlated with slower assembly times. An increase in assembly speed tended to come at the expense of assembly score, and vice versa. Overly intense cognitive engagement in simple tasks actually slowed down assembly. Furthermore, a performance dynamic anomaly was found in simple tasks: monotonous repetition triggered a spike in errors during the final phase of the experiment, reflecting cautious behavior to maintain signal detection precision. Individual differences, particularly personality traits and gamification user types, were identified as influencing performance variability. Neurophysiologically, the point element mitigates digital overload and accelerates the learning curve by enhancing neural efficiency through the reduction of theta, alpha, and beta power in the parietal Pz area, which expedites the transition from knowledge-based to automated skill-based behavior. In contrast, an increase in Cz central alpha activity indicates that a state of cortical idling directly slows down performance. Moreover, FAA analysis shows that point-based gamification serves as an effective stabilization mechanism, suppressing negative emotions during complex tasks. Points act as a germane load that facilitates cognitive schema construction, while badges in complex tasks risk becoming an extraneous load if not properly aligned. A one-size-fits-all design for gamified virtual training is suboptimal. This study recommends an adaptive gamification system that prioritizes badges for speed efficiency in complex tasks and combines elements to promote accuracy.

Keywords: Gamification Elements, Individual Differences, EEG, OpenBCI, Ganglion.